

Study on Indoor Simulation Method of Atmospheric Turbulence and Aerosol Environment

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[Abstract] The atmospheric turbulence is simulated in the laboratory using an atmospheric simulation pool, and the intensity of atmospheric turbulence can be adjusted by controlling the temperature difference between the upper and lower plates of the simulated pool. At the same time, the PM_{2.5} environment was simulated in the simulation pool, and the particle sensor was used to measure the concentration of PM_{2.5}. Since atmospheric visibility is mainly affected by PM_{2.5}, we obtained air quality data for a period of time in a certain area of Beijing, and numerically fit the relationship between the two, and obtained a regression model between the two. The regression model was applied to the atmospheric simulation pool to calculate the visibility of the simulated atmosphere, and compared with the air quality of the Fengtai area published by the Meteorological Bureau, and the accuracy of the simulation pool to the PM_{2.5} environmental simulation was tested. Based on the turbulence simulation, the simulation pool simulates the PM_{2.5} environment. The method is feasible and has sufficient theoretical basis. It provides a reliable indoor experimental platform for future research on laser atmospheric transmission.

[Keywords] Atmospheric simulation pool; Atmospheric turbulence; PM_{2.5}; Visibility; Regression model

1. Introduction

Ideally, the propagation of the laser has a very strong directivity, and beam spread occurs at a longer transmission distance. However, when the laser is transmitted in the atmosphere, due to the action of atmospheric turbulence, the laser will have wave front distortion, beam drift and other phenomena.^[1] Secondly, due to the absorption and scattering of atmospheric aerosols and atmospheric molecules, the energy of the laser will be attenuated and unevenly distributed.^[2] The interaction between laser and atmosphere has a great negative impact on laser ranging, laser communication and laser weapons. Therefore, it is necessary to explore the interaction between laser and atmosphere. However, because the atmosphere itself has strong uncertainty, measuring its characteristics in the field will bring heavy workload and calculation. Therefore, it is a feasible and economical way to simulate the actual atmospheric environment indoors by using the atmospheric simulation pool.

At present, commonly used atmospheric simulation methods include liquid crystal atmospheric turbulence simulators, convective atmospheric turbulence simulators, and simulation methods based on random phase plates. These methods are mainly used to simulate the characteristics of atmospheric turbulence, and the effect is obvious,

which is closer to the real atmospheric turbulence characteristics, but the simulation experiments on atmospheric molecules and aerosols have been studied less. This paper not only simulates atmospheric turbulence using atmospheric simulation pools, but also simulates a certain concentration of aerosol environments such as PM_{2.5} and PM₁₀, and calculates the visibility of simulated atmosphere. The simulation pool is of great significance for the subsequent study of the law of laser transmission in the atmosphere.

2. Basic Principles of Atmospheric Simulation

Figure 1 shows the overall structure of the atmospheric simulation pool. The pool body is a heat insulating material. On the side of the pool body, circular apertures 1, 2 and square openings 3 of equal diameter are respectively opened. They are used to pass the laser beam and install PM_{2.5}, PM₁₀ sensors. Water-cooled panels and heating panels are installed on the upper and lower surfaces of the pool body, and are connected to the temperature display and the controller. The temperature difference between the upper and lower panels is controlled by controlling the heating power of the heating panel. Under the action of the temperature difference, the air inside the pool body convects to form a turbulent flow.

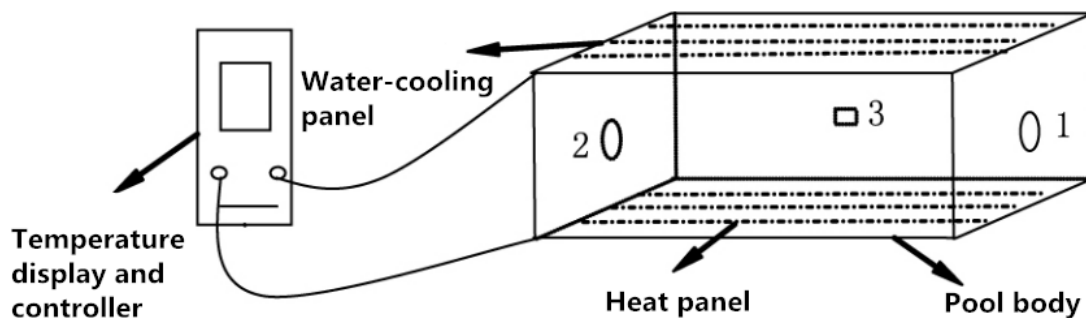


Figure1. Schematic Diagram of the Atmospheric Simulator

2.1 The Basic Principle of Atmospheric Turbulence Simulation

The theoretical basis for simulating atmospheric turbulence in atmospheric simulation pools is the principle of flow similarity, which shows that: The two flow-like conditions are geometric similarity, motion similarity, and dynamic similarity. If the geometric boundary conditions of the two flows are similar and the Reynolds number is the same, even if the two fluids are different in size and velocity.

The two flows will also have similar dynamics. The intensity of the atmospheric turbulence simulated by the atmospheric simulation pool is related to the temperature difference between the upper and lower plates. The temperature display and the controller can adjust the temperature of the two plates separately and display them in real time.

2.2 Simulation Principle of Atmospheric Molecules and Aerosols

The attenuation of the laser by the atmosphere is mainly determined by the nature and structure of the atmosphere itself. The absorption and scattering of laser by atmospheric molecules and the absorption and scattering of laser by atmospheric aerosols are the main factors leading to the attenuation and uneven distribution of laser energy. Atmospheric aerosols are liquid or solid particles with a particle size in the range of 0.01 to 100 μm . PM2.5 and PM10 occupy a major part and are the most important factors affecting atmospheric visibility. At present, the working principle of atmospheric visibility detectors mainly includes transmissive and scattering. For our atmospheric simulation devices, it is obviously inappropriate to use the visibility detector to predict the visibility of the atmospheric environment indoors. According to Song Yu, et al., the correlation between PM2.5 and visibility is better than PM10 and visibility. Therefore, it is considered to use the PM2.5 data published in a certain area to numerically fit the visibility, obtain the mathematical relationship between the two, and then calculate the visibility of the simulated atmosphere according to the expression.

2.2.1 Numerical fitting of visibility

We obtained a total of 184 days of air quality data from July 1, 2016 to December 31, 2016 in the Daxing area of Beijing on the website of the China Meteorological Administration, except for the flood season with missing data, and 143 days. Import the data into Matlab, with PM2.5 as the independent variable x and Visibility VIS as the dependent variable y . Before the data is fitted, the data is first preprocessed. Due to measurement errors and other factors, there may be outliers in the data that deviate significantly from other data, which will have a large impact on the accuracy of the fit, so discard these outliers. The scatter plot is traced in Matlab, and the data that needs to be discarded is marked. In order to ensure the integrity of the data as much as possible, the points where the values of the two pairs of x are relatively close but the values of y differ greatly are shown in Figure 2.

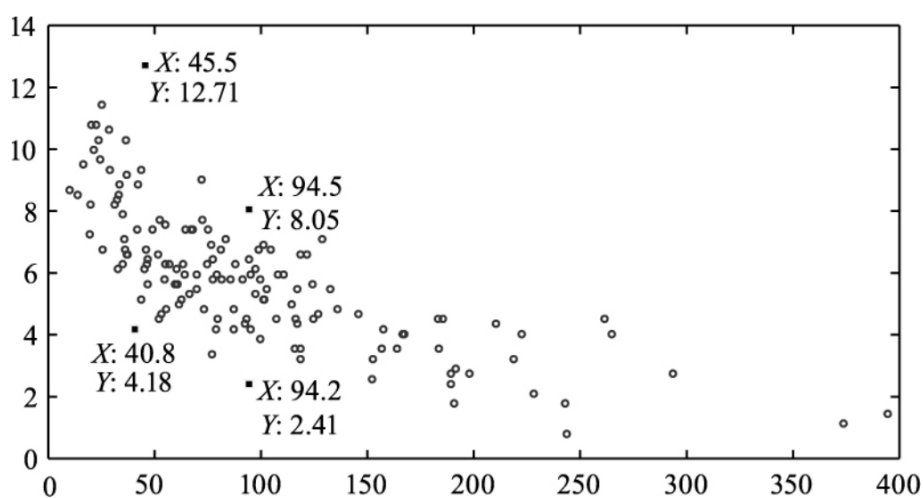


Figure 2. Scatter Diagram of PM2.5 and Visibility Data

According to the trend of the scatter plot, it can be found that there is a good exponential function relationship between PM2.5 data and visibility, assuming that there are regression model equations between the two:

$$y(x, y_0, x_0, k) = y_0 [1 - e^{-(x-x_0)/k}]$$

Among them, y_0 , x_0 , and k are model parameters, and the model parameters can be obtained to obtain the regression model equation. Since the Gauss-Newton iteration method has a fast convergence speed, this method is chosen to solve the nonlinear regression model problem. The iterative idea is to replace the nonlinear model with Taylor series expansion, and obtain the optimal value of the regression coefficient in multiple iterations, and the residual of the model is minimized. Figure 3 shows the fitted curve of the program output.

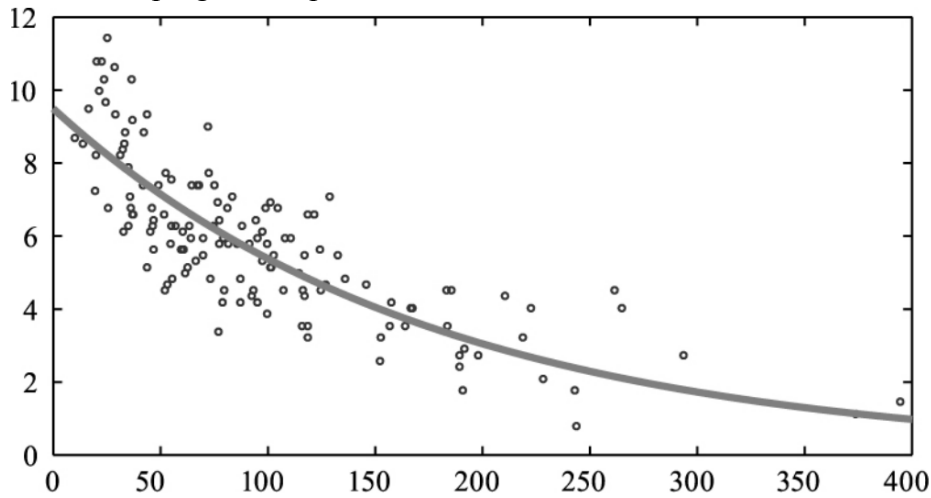


Figure 3. Diagram of the Curve for Data Fitting

2.2.2 Simulated Atmospheric Visibility Calculation

According to the above discussion, the most important factor affecting atmospheric visibility is PM2.5. Therefore, when simulating the atmospheric environment in the simulation pool, the main consideration is how to construct an environment with a certain PM2.5 concentration. Studies have shown that the main components of PM2.5 are sulfates, nitrates, ammonium salts, carbonaceous particles, metal particles, minerals and organic compounds they adsorb. The main sources include automobile exhaust, cigarette smoke and fossil fuels (coal), oil and gas) burning. According to this, the cigarette and a small amount of coal are fully burned in the simulation tank, and after the smoke is sufficiently diffused to the uniform in the pool, the concentration value is measured by the PM2.5 sensor. The SDS021 particle sensor installed at the position of square opening 3 can measure the concentration of particles suspended in air with a particle size between 0.3 and 10 μm . The values of PM2.5 and PM10 are output in the serial port debugging software in the form of hexadecimal messages. The data output frequency is 1HZ, and the output value of PM2.5 ranges from 0 to 999.9 $\mu\text{g}/\text{m}^3$, and the output value of PM10 ranges from 0 to 1999.9 $\mu\text{g}/\text{m}^3$. Accuracy calibration of this type of sensor is required before use. The sensor

measures the PM_{2.5} concentration at the top of the fourth floor of a department (approximately 14 m in height) from 11:00 am on October 26, 2017. Measured every 30 minutes, measuring time is 60 s, select 10 sets of data and find the average value. After measuring three times, the PM_{2.5} mean value is 201 Xg/m³. At the same time, the PM_{2.5} value of the Beijing Fengtai area announced by the Beijing Meteorological Bureau was 227xg /m³. Since the meteorological bureau has multiple stations in the Fengtai area, the published data is the regional average, so we believe that the accuracy of the measurement results of this type of sensor is reliable. Using this type of sensor to measure the PM_{2.5} value in the atmospheric simulation pool, the measurement interval is 30 minutes, and the measurement time is 60 s. For the total amount of control data, only the average of 5 sets of output data is selected, and a total of three groups are measured. The third and fourth bits of the hexadecimal message are the low byte and the high byte of PM_{2.5}, and the fifth and sixth bits are the low byte and the high byte of PM₁₀. When converting the PM value to decimal, first convert the high and low bytes to decimal, and then get the final result according to (high byte x 256 + low byte)/10. The data records are shown in Table 1.

Table 1. Measured Data of PM_{2.5}

Groups	Hexadecimal output	PM _{2.5} Decimal data	Average value
1	AA C0 7A 03 B0 04 B2 80 55 AB	89.0	90.2
	AA C0 8A 03 B3 04 B2 80 52 AB	90.6	
	AA C0 90 03 C2 04 B2 80 59 AB	91.2	
	AA C0 7E 03 B4 04 B2 80 57 AB	89.4	
	AA C0 8C 03 B9 04 B2 80 58 AB	90.8	
2	AA C0 6A 03 B1 04 B2 80 53 AB	87.4	88.3
	AA C0 71 03 CC 04 B2 80 55 AB	88.1	
	AA C0 78 03 B9 04 B2 80 51 AB	88.8	
	AA C0 6F 03 B7 04 B2 80 56 AB	87.9	
	AA C0 7B 03 B4 04 B2 80 54 AB	89.1	
3	AA C0 5F 03 A9 04 B2 80 53 AB	86.3	87.5
	AA C0 6B 03 AE 04 B2 80 57 AB	87.5	
	AA C0 6E 03 AF 04 B2 80 50 AB	87.8	
	AA C0 70 03 B2 04 B2 80 56 AB	88.0	
	AA C0 6F 03 B6 04 B2 80 59 AB	87.9	

The average of the three sets of measurements was averaged to obtain a regression model of PM_{2.5} concentration in the simulated pool of $88.7 \mu\text{g}/\text{m}^3$, which was substituted into the formula, and the visibility of the simulated atmosphere was 3.84 km. Comparing this data with the data released by the Meteorological Bureau, on November 2, 2017, the average PM_{2.5} of the Fengtai area in Beijing at around 11 am was $88 \mu\text{g}/\text{m}^3$, and the visibility was 4 km.

By comparison, It is found that the simulated atmospheric visibility calculated by the regression model is larger than the actual value, but the error is within the allowable range, indicating that the simulation of the atmospheric visibility by the simulation pool is highly reliable, and can be used as an indoor experimental platform for studying the law of laser atmospheric transmission in the future.

5. Conclusion

This paper clarifies the basic principle of simulating atmospheric turbulence of different intensities, that is, controlling the temperature difference between the upper and lower plates of the simulation pool; Based on the air quality data of the Daxing area in Beijing, the regression model between PM_{2.5} and visibility was calculated. At the same time, a certain concentration of PM_{2.5} environment was simulated in the simulation pool and the visibility was calculated. Factors affecting visibility include PM₁₀ and relative humidity in addition to PM_{2.5}.

Therefore, there is a certain error in the regression model with PM_{2.5} as a single variable. From the calculation results, the predicted value is larger than the actual value. Subject to the factors such as equipment and sensor measurement accuracy, the accuracy of the simulation effect of the simulation pool on the atmospheric environment needs to be improved. The concentration of the simulated pool on the PM_{2.5} is not yet actively and accurately controlled.

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