Research on Characteristics of Laser Communication Attenuation in Environment of Fog Patches based on Mie Theory

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Abstract: Laser communication is considered to be a promising technology in long-range communication. A light beam carries information, which facilitates extremely high data rates. In addition, presence of fog patches in propagation channel hampers laser communication as small water droplets scatter propagating. We develop a model of light transmission through fogs of different light transmittance and types using Markov processing simulations. After analysis of hydrometeor scattering characteristics in fog patches, a quantitative result for attenuation of laser energy through scattering process is presented. Laser energy is greatly attenuated caused by high concentration of hydrometeor.

Keywords: Fog patches; Laser communication; Markov processing; Scatter

1. Introduction

Laser communication is considered to be an alternative to radio-frequency links in long-range communication for its attractive features, will be widely used in underwater submarine communications, satellite communications and so on[1]. There are many advantages of wireless laser communication, such as high level secrecy, strong anti-interference ability, large information capacity, high transmission rate, etc. But a large number of molecules, dust and aerosol particles in atmosphere will scatter the laser signal. Researches of wireless laser communication greatly promote applications of laser in communication, radar, remote sensing and detection[2]. Therefore, transmission characteristics of atmospheric environment shall be studied for sake of wireless laser communication system gradually achieve application, we must study on account of transmission characteristics of atmospheric environment.

There are plenty of minute hydrometeor particles formed droplets in air, which will cause laser energy attenuation during transmitting procedure of laser communication, by absorption and scattering[3]. Fog patches is a kind of small scale, high concentration and low visibility fog, which is formed suddenly in fog area. Therefore, it is necessary to study fog environment that may be regarded as a single weather phenomenon. Research about laser communication attenuation in environment of fog patches aiming to promote performance of wireless laser communication.

2. The Existing Research Direction and Method

Scholars mainly focus on three aspects of laser propagation process in fog environment. They are mainly in fog environment, base on the application of Mie scattering theory or Rayleigh scattering, to issue qualitative or quantitative analysis after experimentation.

Firstly, to study theory of laser transmission in environment of fog. Some researchers use single scattering theory to analyze relationship between moisture content in fog and laser radar system[4]. And Others study characteristics of Gaussian light spreads through heavy fog environment.

Secondly, to determine size distribution of fog droplets. Fog droplets spectrum is very difficult to measure. However, determination of dynamic characteristics is more difficult because fog particles are susceptible to change its basic character. Research has shows that in process of fog formation, size distribution of fog drop tends to large particle, whereas dispersal process is just opposite[5].

Thirdly, to analyze attenuation of laser in fog, base on qualitative and quantitative research. This aspect mainly concludes research of real data obtained by measuring, and analysis of data processing to get a suitable for fog attenuation empirical formula. David et al. study attenuation change when infrared transmission in environment of artificial fog[6]. Especially, some scholars take double isotropic particle degradation is isotropic particle. Its calculated results and generalized Mie theory calculation

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of surface of the scattering field, diamond, field distribution results be identical perfectly, to a certain extent, we can find hydrometeor particles as isotropic particle absolutely[7].

3. The Formation and Characteristics of Fog Patches.

Fog is a sort of weather phenomenon which caused by the particles with a large number of water drops or ice crystals in air suspending close to ground, usually, its horizontal visibility distance less than 1 km. Radiation fog is the most common one, of which of which development is closely related to cold air activities. Fog patches is a kind of small scale, high concentration and low visibility fog which formated suddenly and influenced by regional topography, landform and local special climate environment. Fog patches is arise from local water vapor radiative cooling. So it easily appear under radiation fog environment when surface layer water vapor condition is appropriate. Fog patches is essentially a special type of fog formed by non-uniform distribution hydrometeor. The difference between fog patches and fog is small area covering and inconsistent range in size. Generally, a large fog patches covers about five kilometers long, and small fog patches only about one kilometer.

4. Simulation for Attenuation in Environment of Fog Patches

The absorption of fog particle scattering is more serious than atmospheric molecules, but smaller than fog particle scattering effect at least an order of magnitude, size of fog particles generally in the range of 1 ~ 100 μ m. So , we consider fog particle scattering of laser as the main aspect in study of interaction with laser and cloud or fog. Laser transmission loss caused by fog can use Mie scattering theory to calculate and forecast, it mainly depends on the size and density distribution of scattering particles. Direction of Mie scattering is more obvious, take forward scatter as the principal thing, as shown in Figure 1. For coagulation of particles in atmosphere, due to effect of particle surface tension, particle shape close to sphere, and because particle size is so small, so it also can be regarded as isotropic spherical particles when analyzed by statistics[8].

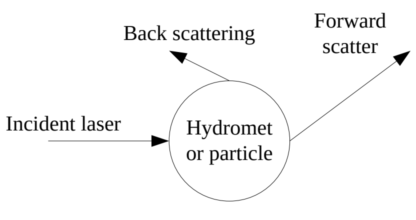

Figure 1. Direction of Mie Scattering

Mie scattering of scattering intensity mainly concentrated in forward scattering, and its strength than Rayleigh scattering. Through definition of Mie scattering phase function, we can effectively calculate probability of particle size distribution, by Mie scattering phase function, we can get phase function of three types of fog and haze, their size distribution curve is shown in Figure 2.

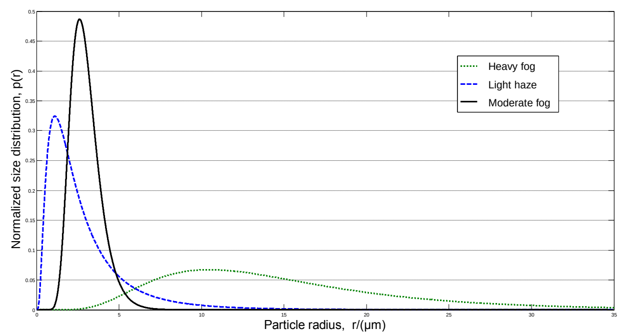

Figure 2. Normalized Size Distribution of three Types of Fog, Haze

The light may be seen as a large number of photons, each of which traverses transmission medium until encountering a particle, when it is scatter in accordance with scattering functions described above, absorption is ignored, since imaginary part of water's index of refraction is very small.

According to fog attenuation equation of single scattering theory[9], in this present paper we examine a new measure of fog patches. We shall first briefly calculate base on single scattering theory of attenuation rate, combining particle movement can meet requirements of Markov property, simulation test of laser pulses in through fog area and fog patches after attenuation of laser. Attenuation and evolution of each step in process of laser propagation, are not affect by before evolution.

By the definition of attenuation, we can get formula (1), PR' and PR, respectively, with or without fog particles when receive power of the receiver, A is attenuation rate, usually express in units dB/m, when z=1m. It means wave of 1 meters, relative value of transmitting power and receiving power[10].

$$P_R = P_R' e^{-Az} \qquad (1)$$

In receiver, power of signal, normalized to 1-W transmitted power, may be summed up as (2), where is FOV angle, is pointing error, is optical density, is radiation wavelength, is aperture size, and Q represents scattered light received.

$$P_R(\alpha,\phi,\lambda,\delta,\omega) = \int_{\phi-\alpha/2}^{\phi+\alpha/2} Q(\alpha,\lambda,\delta,\omega)d\alpha \qquad (2)$$

Optical density is defined as a material characterization of shading ability. It is logarithmic for ratio of incident light and transmission light, on the other words, it is logarithms of light transmittance inverse. So, when other conditions unchanged, laser attenuation rate has direct relationship with light transmittance, and they are inverse proportion.

Base on this theoretical basis, we can establish a laser attenuation model of fog patches, base on results of Mie scattering theory, we can deduce fog attenuation equation of single scattering theory[11]. This paper use laser attenuation rate from Mie scattering theory, and combination of special conditions that particles move in accordance with Markov property, we simulate laser attenuation situation after its through fog patches area, its evolution of each step in its evolution and propagation process, is not affect by before process.

We assume that each laser beam carrying 1000 photons from transmitter, after laser through fog area contains fog patches with settled light transmittance, in receiver, photons number of signal will be a certain degree of attenuation, in case of different transmittance, attenuation is different, and level of attenuation and ratio of fog patches to all fog area have direct relation. Its simulation working flow chart is shown in Fig.2. Base on simulation of a beam of laser, it can be concluded that mean value of number of remaining photons after laser passes through fog, by changing light transmittance and proportion of fog patches, we can get laser photons number attenuation curve(see Fig.3). On premise of many experiments, we can get variance of number of remaining photons in each group of experiments(see Fig.4).

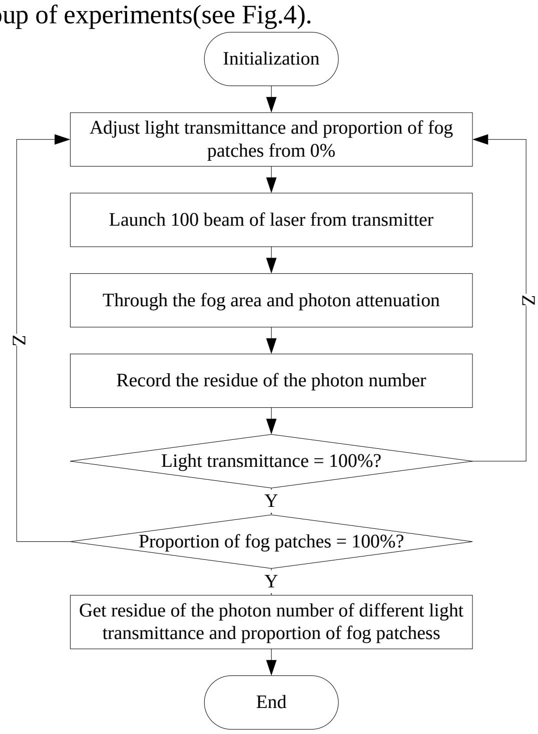

Figure 2. Laser Communication Attenuation Simulation Flow Chart

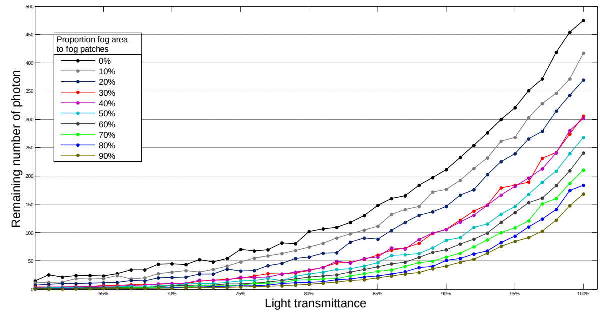

Figure 3. Laser Photons Number Attenuation Curve

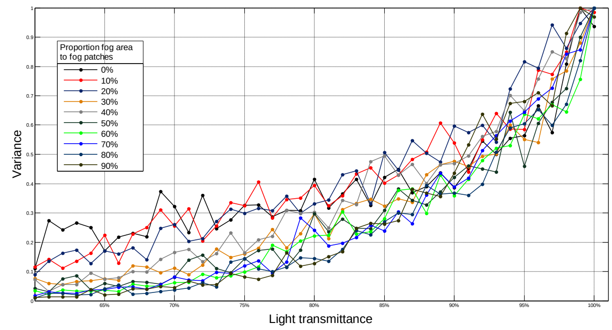

Figure 4. Variance of Number of Remaining Photons

Adjust the size of the light transmittance is actually change of visibility, with increase of light transmittance, after through fog patches area, average value of remaining photons had obvious increase, meanwhile, decrease in fog patches area proportion of fog group, average value of remaining photons had obvious change. In Fig.3, we can find in the case of proportion of fog patches is constant, variance of number of remaining photons in each group of laser beams had rolling increase with increase of light transmittance, reflects fluctuations in the data to us.

5. Conclusion

Base on Mie scattering theory, we find that there is a direct relationship between the particle density and laser signal attenuation, particle density can be reflect from visibility, so we analysis laser signal attenuation characteristics of light transmission in fog patches environment, and focus on analyzing fog patches attenuation channel model, simulation analysis in Matlab platform. Simulation results demonstrate that attenuation of laser signal is affected distinctly by visibility of fog environment. With reduction of visibility, attenuation of laser generated trends to increase. Attenuation of laser energy is influenced by two aspects, transmittance and proportion of group fog patches. Especially after laser signal through a fog patches area, attenuation rate will increase significantly. This phenomenon will expected to seriously limit quality of optical communication system.

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