Preliminary Study on the Characteristics of Laser Underwater Proximity Transmission

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Abstract. Due to the special circumstances of underwater channel environment, laser underwater communication technology is facing challenges. The characteristics of underwater channel have been simulated and tested in this paper. Firstly, the scattering model and Monte-Carlo simulation method based on Mie scattering are established. Secondly, the simulation test on the influence of laser transmission under different parameter conditions is carried out. Finally, the design of the laser signal receiving system and the laser underwater transmission experiment are designed. The method of reducing the signal to noise ratio is analyzed and put forward. The experimental research is also carried out to verify the correctness of the simulation results. The experimental results show that with the increase of transmission distance, the diameter and density of scattering particles, the time domain broadening, space broadening and energy absorption of the laser will reduce the received light energy transfer signal, the sine wave will be distorted and the transmission will be affected effectiveness.

1. Introduction
At present, compared with acoustic communication technology, optical communication technology has a higher rate and broadband advantages, laser underwater communication technology is developing rapidly. The study on underwater short-range transmission characteristics of fuze is an important part of fuze communication technology and fuze to target detection technology, and has great significance to the interactive communication between underwater intelligent weapon and command station [1-2]. Based on the technical requirements of laser underwater communication and the characteristics of seawater, the research on the characteristics of laser underwater communication and the experiment to find out the influence of channel environment on underwater short-range communication are very important for the improvement of communication efficiency [3].

2. Photon Transmission Characteristics under Water

2.1 Underwater Optical Scattering
The physical properties of various particulate matter and soluble matter in seawater together influence and determine the main optical properties of seawater. The combination of light scattering and absorption causes the beam to decay in seawater. During the transmission of laser light in seawater, Mie scattering in seawater plays a leading role.

2.2 Mie Scattering Theory
Given the Mie scattering phase function, the scattering phase function is defined as: The scattering phase function is the unit cube angle scattered light averaged over the scattering intensity and the full-
angle range for the integral laser at the unit solid angle centered at a given direction θ. Strong ratio, the symbol for the β(θ), and the relationship is \[ \beta(\theta) = \frac{df(\theta)}{Ed\theta} \]. Mie scattering phase function is

\[ p(\theta) = \frac{4\pi\alpha(\theta)}{\sigma_s} \] (1)

When \( \alpha(\theta) \) is the angular scattering cross section, and \( \sigma_s/4\pi \) is the average of the angular scattering cross section over the full angular range. Regarding the marine particles that affect the refractive index of seawater, the refractive index of the inorganic particles is larger than the refractive index of biological suspensions such as green algae. In this paper, the simulation experiments are based on the experimental results of Armstrong (1965), Pavlov and Grechushnikov (1966)) to select the relative refractive index. Combining the Mie scattering and Rayleigh scattering models, the scattering directions of photons in the underwater environment are simulated. The results are shown in the figure.

![Figure 1. Contrast of the scattering underwater environment](image)

In Figure 1, the positive y-axis is the incident direction of photons. It can be seen that photons scatter backwards in the seawater environment except for a small amount of photons, and most of the scattering directions are the forward-consistent forward scattering in the incident direction. Asymmetric factors in scattering are above 0.95.

In this paper, the scattering model has been simplified as the Mie scattering model, Monte Carlo simulation method combined with Mie scattering analysis model to simulate the laser underwater short-range transmission [4].

### 3. Simulation and Result Analysis

In the simulation of this paper, the parameters of the free movement distance and scattering elevation angle of the photon are randomly chosen and the probability of distribution is uniformly distributed. At the same time, 106 photons are emitted at one time, and the final arrival of the receiving surface is obtained.

#### 3.1 HG Scattering Phase Function

Since the Mie scattering is verified to be much greater than the backscatter in seawater, a scattering phase function suitable for the Mie forward scattering model needs to be proposed. The most commonly used is the Heney-Greenstein scattering phase function, hereinafter referred to as the H-G phase function, which is expressed as

\[ p_{HG}(\theta) = \frac{1 - g^2}{4\pi(1 + g^2 - 2g\cos\theta)^{\frac{3}{2}}} \] (2)

In the formula, \( \theta \) is the scattering angle, \( g = <\cos\theta> \) is the asymmetry factor, and is also the
average of the cosine of the scattering angle. The traditional H-G scattering phase function is suitable for the scattering angle of \(-\pi/2\sim\pi/2\), that is, forward scattering.

By the definition of scattering phase function we can see that, \(p_{HG}(\theta)\) meet

\[
2\pi \int_{-1}^{1} p_{HG}(\theta) d\cos\theta = 1
\]

(3)

And because \(g = \langle \cos\theta \rangle\) is an asymmetric factor, is the average pre-selected scattering angle, available after changes

\[
2\pi \int_{-1}^{1} p_{HG}(\theta) \cos\theta d\cos\theta = g
\]

(4)

Bringing \(a_n, b_n\) into the calculation formula of relevant effective coefficient, the asymmetry factor can be numerically simulated, and the correlation between asymmetry factor and particle size coefficient can be obtained.

3.2 Numerical Simulation of Scattering Coefficient and Extinction Coefficient

The relationship between scattering coefficient and extinction coefficient is

\[
k_{ext} = k_{sca} + k_{abs}
\]

(5)

And \(k_{sca}\) is the scattering coefficient, \(k_{abs}\) is the absorption coefficient, \(k_{ext}\) is the extinction coefficient.

Using Matlab to calculate and simulate \(K_{sca}\) and \(K_{ext}\), we can see from Mie theory that Mie scattering occurs when the wavelength of incident light is equal to the size of scatterer. The wavelength of incident light is set as \(\lambda = 450\text{ nm}\) and the relative refractive index is \(m = 1.34 - 0.05i\).

3.3 Monte Carlo Simulation Process

![Figure 2. Monte Carlo simulation flow chart](image)
Through the Mie scattering model, the variables in the analytic formula are changed to get the independent variables of the photon movement matrix. Combined with the Monte-Carlo method, the photon transport process and the result are simulated to obtain the relationship between the photon weight and the number of scattering under different conditions figure 2.

3.4 Simulation Results and Factor Analysis of Photon Underwater Transmission

Figure 3 shows the average weight of photons reaching the receiving device obtained by Monte Carlo simulation of photon transmission under different conditions. Each time they emit $10^6$ photons, and magnify the average weight in Figure (a) by 1000 times for observation and analysis.

Combining the Mie scattering analysis model and the Monte Carlo simulation, we can see that with the increase of the diameter of the scatterer, the density of the scatterer and the increase of the transmission distance, the weight of the photon reaching the receiving surface decreases. When the density of the scatterer is $\geq 10^{13}/m^3$, the receiving distance is $\geq 3m$, the arrival of the receiving surface photon weight close to 0; as the particle diameter increases the number of photons scattering increases, especially the increase of backscattering, the receptive surface photon weight is greatly reduced. The increase of distance and the increase of the density of scatterers also cause the multiple scattering and the large attenuation of energy and the severe broadening of the beam space, resulting in a sudden drop in weight reaching the receiving plane and insufficient energy for the photon energy required for time broadening.
Simulation of light beam in the underwater transmission space broadening phenomenon what the experimental results shown in Figure 4. The beam broadening does not increase with the propagation distance, and the photon weight decreases with the propagation distance.

Figure 4. Beam spread in different propagation distances
As shown in Figure 5, the spatial spread of the photon number is related to the number of scatterings, and increases without accounting for the decay of the scattering energy.

4. Blue-green Laser Underwater Communication Experiment

4.1 Design of Underwater Laser Transmitting and Receiving Circuit

![Receive sine wave counting circuit](image)
Because of the simple functions of the system and the underwater environment involved in this article, the laser emitting device in the test equipment cannot be coded. Therefore, the experiment is conducted by using the sine wave technology communication method [6]. The selection of STM32 laser sinusoidal count, the counting circuit shown in Figure 6.

Combined with the experimental requirements, the design of the relevant overall system architecture, the combination of the overall receiver, the system block diagram shown in Figure 7.

![Figure 7. Receive system components](image)

4.2 Noise Analysis
For the experimental system, the main noise sources are optical excess noise, quantum scattering noise, optical background noise, dark current noise of optical detector, excessive noise of optical detector and electronic noise. Use the following methods to improve the signal to noise ratio:

Adopt PIN tube G0606M-G and FET input operational amplifier AD8065 with smaller noise factor to effectively reduce excessive noise and electronic noise;

1) The use of high penetration infrared cut-off green filter, effectively filter out the optical background noise;

2) Put a pair of similar photodiodes in the non-inverting input of the op amp of the preamplifier to effectively compensate for the dark current.

4.3 Experiment and Result Analysis
Underwater laser transmission experiments using an external sine wave modulation laser launcher, the laser modulation frequency of 3kHz, the laser wavelength of 320nm, underwater scattering particles density $10\mu g/\text{m}^2$, get the maximum laser underwater communication distance of 10m.

Experiments simulate the underwater environment, adding algae plants, fine mud and decaying animal and plant debris to the water tank to change the water environment [5]. Use a sunshade above the sink to prevent the sun from over-suing. Using USB2811 data acquisition card acquisition experimental data, respectively, were processed as shown in Figure 8-10 below the experimental results.
Figure 8. Voltage signal with the transmission distance curve

Figure 8 shows that with the increase of transmission distance, the laser attenuation is serious, which is more serious when it contains 10μg / m³ of underwater particles compared with pure water.

Figure 9. Voltage signal changes with density curve
Figure 10. Voltage signal with the particle diameter curve

From the experimental results, it can be seen that during the underwater transmission of photons, the energy is seriously attenuated after Mie scattering, and serious time broadening and space broadening effect will occur. The weight of photons decreases rapidly with the increase of transmission distance, scattering particle diameter and density. The number of single-photon scattering increases with the size of the scattering particle diameter, and the time broadening does not increase with the particle size. Analysis of the reasons for the discovery is due to the larger particle size, the photon in the transmission of energy attenuation is more serious, to reach the receiving end of the weight is not enough to form a time broadening. Experimental results and simulation results are basically the same.

5. Conclusions
In this paper, we start with the photon underwater transmission characteristics and study the influence of the channel environment on the communication in the laser underwater short-range communication. In the simulation method, combined with Mie scattering analysis model and Monte-Carlo simulation, the laser underwater transmission experiment was carried out to verify the Monte Carlo simulation of the underwater environment on the laser transmission characteristics of the results, and to improve the signal to noise ratio the specific method.

6. References
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