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UNDERWATER WIRELESS OPTICAL LINKS WITH ON-IMPULSE RESPONSE

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ABSTRACT

In this study, we look at the temporal features of underwater wireless optical communication (UWOC) links as defined by impulse response. Using the Henyey-Greenstein model, the impulse response has a model of scattering phase function. Monte Carlo simulations for turbidity have been obtained. Coastal and harbour water are examples of underwater environments. A double Gamma function has been expressed in closed form. Curve fitting methods were used to represent the simulated impulse response. The double Gamma, according to numerical results, The impulse response in turbid seawater is well represented by this function.

Keywords: Underwater Wireless Optical Communications, Impulse Response, Monte Carlo.

I. INTRODUCTION

In recent years, underwater wireless optical communications (UWOC) has gotten a lot of attention. The UWOC networks transfer data using visible light in the blue/green spectrum. As this location has the lowest absorption of saltwater, data is scarce. Traditional acoustic linkages are being replaced by a new technology called acoustic links. The optical cables may deliver a substantially greater data rate of up to 1 Gigabit per second over relatively small distances. In addition, the UWOC systems overcome other acoustic drawbacks such multipath reflections and excessive latency There are various advantages to using this strategy, applications such as high-definition video transmission, real-time monitoring, effective resource exploitation, and a high level of security networks with high throughput.

However, multiple scattering of light causes temporal stretching of the beam pulse, which causes inter-symbol interference (ISI), which limits channel bandwidth and degrades bit-error-rate (BER) performance, especially in murky coastal and port waters. In recent years, some previous theoretical and experimental studies on the temporal spreading of light pulses during propagation in saltwater have been published. The pulse spreading and channel bandwidth in seawater were measured by Cochenour et al. , Jaruwatanadilok and Gabreil et al. used vector radiative transfer theory and the Monte Carlo method, respectively, to investigate the impulse response of UWOC links theoretically. However, no straightforward closed-form expression of the impulse response for UWOC linkages has been described in earlier research, to our knowledge.

II. METHODOLOGY

In this research, we use the Monte Carlo model for turbid environment to analyse the impulse response and give a closed-form expression of double Gamma functions to represent the temporal dispersion of UWOC links characterised by the Henyey-Greenstein scattering phase function. The double Gamma function appears to be valid for describing the simulated impulse response for turbid underwater environments such as coastal and harbour water with limited root-mean-square error, according to simulation data (RMSE). For underwater channel modelling and UWOC system design, this simple closed-form formulation is feasible and convenient.

III. MODELING AND ANALYSIS

(1). Scattering phase function

Through the beam propagation, each photon interacts with the saltwater through absorption and scattering. Photons lose energy when they interact with seawater, which is referred to as absorption. Changes in the environment are referred to as scattering. for each photon emitted as a result of interactions with the particles

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in suspension a(λ) and a(λ) are the absorption coefficients. The scattering coefficient b(λ) in inverse metre units is employed. to calculate the amount of energy lost due to non-scattered light as a result of absorption and scattering. The level of attenuation The overall effects of c(λ) = a(λ) + b(λ) are indicated by the coefficient c(λ) = a(λ) + b(λ). Energy loss due to absorption and dispersion a(λ),(b(λ) and c(λ) are affected by the wavelength of the source as well as the wavelength of the target as in water turbidity.

As a result of multiple scattering, each photon's transit time from the source to the detector may change, causing the beam pulse to spread temporally. The scattering phase function (θ) is used to depict the energy distribution of scattering light for a certain scattering angle to describe the multiple scattering process, with the property as follows:

$$1 = 2\pi \int_0^{\pi} \beta(\theta) \sin\theta d\theta \quad ....(1)$$

The Mie scattering is the main scattering in the underwater optical channel when the wavelength of visible light is comparable or less than the diameters of most suspended particles in saltwater. Because of Mie scattering, scattering light concentrates primarily in tiny forward angles [7], (θ) is highest in the small angle area. In the blue/green visible light band, Petzold measured the scattering phase function for typical water types. However, the measurement data has a reduced angular resolution, especially for big measurements. The precision of Monte Carlo simulation results is limited by angles. As a result, we use the Henyey-Greenstein function as the scattering phase function, which has the following form:

$$\beta(\theta) = 1 - g\ 2/4\pi(1 + g^2 - 2g \cos \theta)^3/2 \quad ....(2)$$

where g is the average cosine of θ and θ is the distributed angle.

The Henyey-Greenstein function is commonly used to describe dispersive media like clouds and seawater. For g = 0.924, the average value of Petzold's measurement corresponds well with the Henyey-Greenstein function. We primarily focus on turbid environments such as coastal and harbour water in this work because the impulse response of clean ocean has been researched. The properties of these two water types are the same as they were before.

Table 1. Blue/Green Light Parameters In Coastal And Harbor Water

Water Type	a	b	c	g
Coastal	0.088	0.216	0.305	0.9470
Harbor	0.295	1.875	2.170	0.9199

(2). Monte Carlo Simulation

The above-mentioned absorption and scattering processes can be explained mathematically using the radiative transfer equation (RTE). The RTE can be solved using either Monte Carlo or analytical methods. Monte Carlo methodology uses a numerical method to obtain channel characteristics by producing a large number of photons and then statistically simulating their interactions with the medium. When compared to analytical solutions, the Monte Carlo method is more adaptable to different system geometries and does not impose any limits on photon propagation. We validated the validity of the Monte Carlo technique in predicting both spatial and temporal features by comparing simulations with experimental results. As a result, in order to obtain the impulse response, we used the Monte Carlo method.

Creating numerical photons is the first step in the Monte Carlo simulation. A fundamental set of properties is assigned to each photon, including its position, transmit direction, propagation duration, and weight. Changes in these basic properties along the propagation path are used to represent absorption and scattering processes. Each photon's properties are subsequently recorded by the receiver. By statistically repeating the aforementioned operations for each emitted photon and examining the basic features for all arrived photons, the channel characteristics may be determined.

The position of each photon in Cartesian coordinates (x, y, z), the direction of flight given by zenith angle θ and azimuth angle φ in spherical coordinate system, weight W, and propagation time t are all features of each photon. When the emission aperture of the source is narrow, the beginning position of each photon can be labelled as (0, 0, 0). The start time and weight are both set to zero and unit. The angular intensity distribution and divergence of the source then determine the direction of emission for each photon. When a photon propagates Δs distance given by, the photon interacts with the medium.

$$\Delta s = -\ln \xi s/c, \ldots\ldots(3)$$

where ξs is a uniformly distributed random variable in the range [0, 1]. The position and propagation time of each photon can be altered when the trajectory between two encounters, Δs is established.

The photon's weight and transmit direction are both modified as a result of the encounter. By updating the weight,

$$Wi+1 = (1 - a/c)Wi \ldots\ldots(4)$$

where Wi denotes the photon's weight after the i-th collision with the medium. Due to the scattering effect, the direction of photon flight is also varied with the scattering zenith angles θs, as shown by

$$\xi\theta = 2\pi \int\Big|_0^{\theta s} \beta(\theta) \sin\theta d\theta \ldots\ldots(5)$$

where β(θ)is the scattering phase function and ξθ is a random variable with uniform values between 0 and 1. (5) can be transformed to for the Henyey-Greenstein scattering phase function with g not equal to 0.

$$\cos\theta s = 1/2g\,(1 + g\hat{}2 - (1 - g\hat{}2/1 - g + 2g\xi\theta s)\hat{}2 \ldots\ldots(6)$$

The scattering azimuth angles φs can be calculated using

$$\varphi s = 2\pi\xi\varphi \ldots\ldots(7)$$

where ξφ is uniformly distributed as a random variable in the range [0, 1]. It's worth noting that the scattering angles in (5) and (7) represent rotations in the direction prior to contacts. As a result, the photon's direction should be translated into the absolute coordinate system, as described in [6].

When a photon's weight falls below a specific threshold or reaches the receiver plane1, it should no longer be tracked. The photon should be eliminated from simulations in the first situation. The lowest weight barrier is set at 10^-6 in this research. For each photon, the four properties of position, direction, propagation time, and weight are recorded in the later instance.

The impulse response can be obtained by producing a histogram of the weight of received photons vs propagation time after repeating the aforementioned procedures for each photon and storing all the features of detected photons. The channel impulse response is the result that describes the received intensity with a specified propagation time for a unit emitted intensity. In this work, the time resolution is designated as 10^-10 s.

(3). Double Gamma Function

Several functions have been used to simulate the impulse response in free space optical (FSO) communication lines. According to reports, the single Gamma function represents Non line of sight NLOS geometry pulse form as well as locations with long attenuation lengths [12]. The level of attenuation length is calculated by multiplying the attenuate coefficients. In that work, the link range is greater than 30. The high price in these cases, order scattering light dominates. Low-order scattering light makes a minor contribution, which demonstrates that a single Gamma function can be used to model the impulsive reaction Large power consumptions, on the other hand, Since the diffused light field is required in these scenarios, may form on the receiving end, which is difficult to accomplish in practise

Gabriel et al. investigated the impulse response in clean ocean with attenuation lengths less than ten and concluded that temporal dispersion in clean water is insignificant.

We explore a precisely aligned UWOC system with line-of-sight (LOS) for short attenuation lengths where the diffused light field may not form at the receiver side in this study. The single Gamma function is no longer sufficient to simulate the impulse response because the contribution of lower scattering or ballistic photons may not be negligible in this scenario.

Motivated by the use of double Gamma functions to model the measured impulse response of a wireless optical channel in a dispersive cloud medium with a blue-green laser source, we use double Gamma functions to model the impulse response of a wireless optical channel in a dispersive cloud medium with a blue-green laser source

$$h(t) = a(t - t0)e\hat{}{-b(t-t0)} + c(t - t0)e\hat{}{-d(t-t0)},\ t \ge t0 \ldots\ldots(8)$$

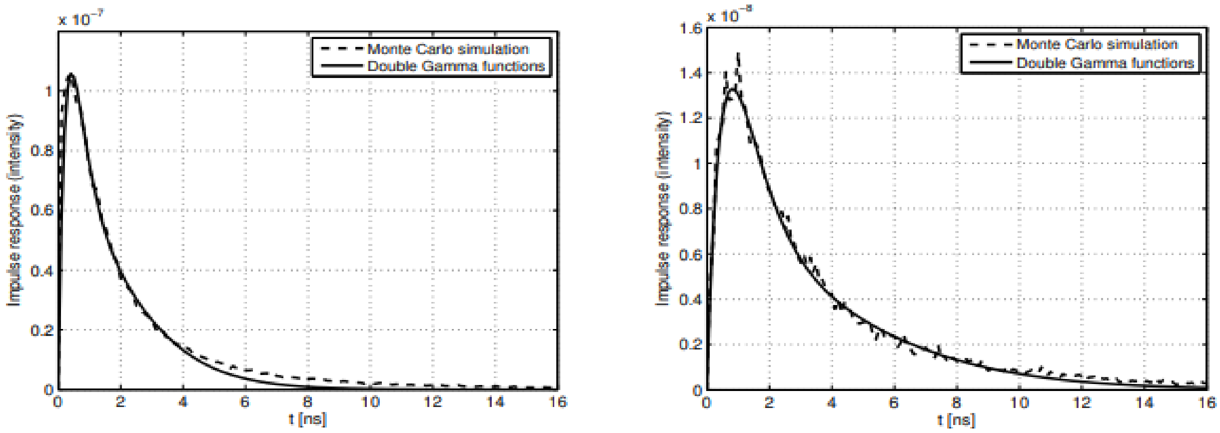
$t0 = L/v$ is the propagation time with link range L and light speed v in water, where (a, b, c, d) are the parameters to be determined, t is the time scale, and (a, b, c, d) are the parameters to be calculated. Eq. (8) is the sum of two single Gamma functions, one for the low order scattering component and the other for the high order scattering component of incoming light.

The collection of parameters (a, b, c, d) can be calculated using the nonlinear least squares criterion given by Monte Carlo simulation

$$(a, b, c, d) = \arg\min_{(a,b,c,d)} \int | \; ([h(t) - hmc(t)]2\, dt), \text{........(9)}$$

where h(t) is the curve fitting model in (8) and hmc(t) is the impulse response Monte Carlo results. We examine a photon detector with a 50 cm aperture and 180 FOV and a 532 nm light emitting diode (LED) with a 10 divergence angle (full angle) (full angle). To acquire the impulse response, we use Monte Carlo simulation using at least 109 photons, and then apply (8) and (9) to evaluate the double Gamma functions model for each of the link ranges and water types illustrated in Fig. 1 and Fig. 2. In these figures, the start time of the impulse response is altered from t0 to zero, and the observation intervals are given as [0,16] ns.

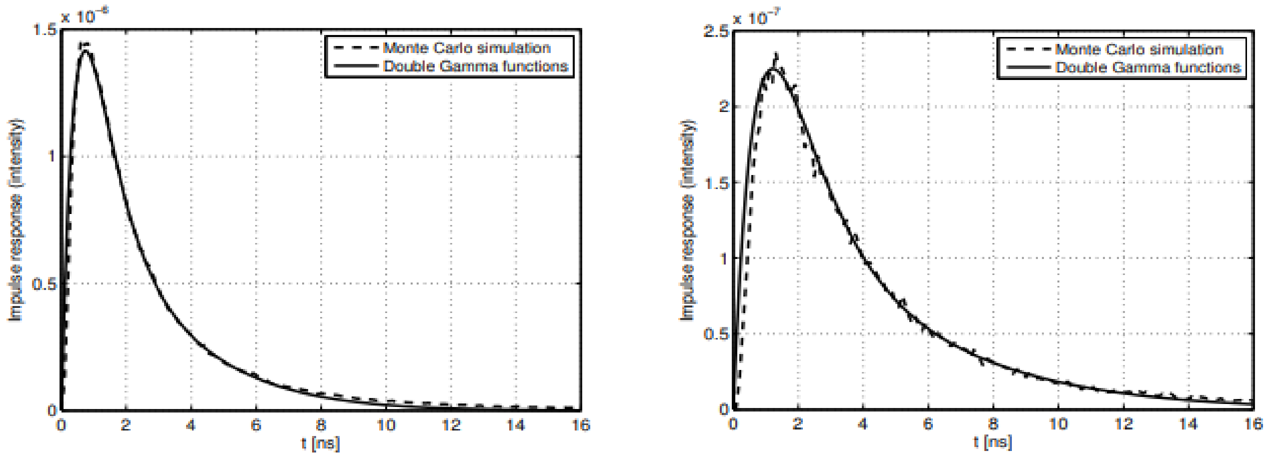
IV. RESULTS AND DISCUSSION



(a) $L = 50$ m link. (b) $L = 60$ m link.

Figure 1: shows the impulse response of coastal water

The double Gamma functions model matches well with Monte Carlo simulations, as seen in Figures 1 and 2. We can see that the impulse response disperses more with each type of water. As the range of the link expands, it becomes increasingly important. This makes sense because the for a longer scattering time, photons are subjected to substantially more scattering, length and are subjected to substantially higher attenuation, lowering the magnitude of the impulse response. The root-mean-square error is a type of error that occurs when a number is multiplie, Table II summarises the root mean square error (RMSE) for all cases.



(a) $L = 10$ m link. (b) $L = 12$ m link.

Figure 2: shows impulse response in harbor water

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Table 2. For Various Scenarios, The Rmse Of The Double Gamma Functions

Coastal		Harbor	
Link Range	RMSE	Link Range	RMSE
30m	0.01272	10m	0.01009
40m	0.03033	12m	0.02191
50m	0.04276	14m	0.01319
60m	0.00889	16m	0.01233

The model of double Gamma functions is numerically validated. It's worth noting that the model with two Gamma functions may fail down in the light field's diffusion area, where the attenuation Since the length is long or the link geometry is mismatched, The amount of lower-order scattering light will decrease. Modeling of the channel impulse response may be influenced by system parameters such as source divergence, detector aperture size, and FOV. The shape of the impulse response and valid region of the double Gamma functions may also be affected by channel coefficients such as the type of scattering phase function and scattering albedo specified as b/c. The above-mentioned themes are deserving of a thorough examination in our future work.

V. CONCLUSION

The impulse response of UWOC links with precisely aligned LOS geometry in a turbid underwater environment was examined in this research. To simulate the impulse response, a closed-form version of the double Gamma function is devised. For various water kinds and link ranges, numerical results from the Monte Carlo technique reveal that the impulse response follows the double Gamma functions, which is useful for system design and performance evaluation. Our future effort will consist of experimental validation of the double Gamma functions concept.

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