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Maintaining LOS in UWOC by Gradient Descent Optimization Algorithm

Liangliang Han*

College of Electrical & Information Engineering, Southwest Minzu University, Chengdu, China

Abstract

With abundant Marine resources, more and more countries support ocean development. Underwater wireless optical communication technology has developed rapidly. Underwater wireless optical communication（UWOC）system is based on light-emitting diode(LED), as a low-power,low-cost and high-data. However, it needs a tolerance interval link between the transmitter and the receiver. UWOC is challenging to maintain line of sight in alignment target due to interference 0f absorption and scattering of underwater. To make the alignment algorithm applied in UWOC, the laser alignment technology is introduced firstly, and the alignment technology based on light intensity is analyzed, which lays a theoretical foundation for the introduction of the gradient descent algorithm. Then the realization steps of the gradient descent optimization algorithm(GDOA) with less computation and high tracking accuracy were analyzed and summarized.

Keywords

UWOC, alignment, gradient descent algorithm(GDOA).

1. Introduction

Alignment technology is the basis of underwater optical communication. To solve the underwater wireless optical communication alignment problem, researchers have proposed several solutions, such as master dynamic alignment control, multi-array reception, and use of divergent beams or increase the area of the receiver. To achieve reduced alignment difficulty and automatic alignment for the purpose.

In 2008, Pontbriand of the WoodsHole Oceanographic Institution, used a large divergence angle LED light source to increase the field of view of the receiver by using a large area receiver (photomultiplier tube) to receive the optical signal directively. In the optical communication process, the need for alignment and tracking mechanisms is avoided due to the increase of receiver receiving range[1]. In 2012, Ian C.Rust of MIT used multiple photovoltaics in LED wireless optical communication systems， the diode was distributed at the receiving end, and the feedback control was adopted by analyzing the received light intensity, aligned the receiver actively with the transmitter end [2]. In most of the above experiments, the link alignment can be reduced by increasing the beam divergence angle or using multiple receiving detectors. But, it will also cause the reduction of the transmission distance of communication, the increase of system complexity, and other problems. Alignment using the advantage of GDOA can make a breakthrough in these problems.

2. Methodology

2.1. Spatial distribution of light intensity

Alignment use of the gradient descent optimization algorithm, firstly, the underwater light intensity distribution should be quantitatively analyzed, and a light intensity distribution model

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should be determined, which can help verify the effectiveness of the gradient optimization algorithm in the simulative experiment. The transmission theory of wireless light in seawater is the basis of constructing light intensity distribution. Light propagation in water will be affected by seawater absorption and light beam scattering, and the sum of the two is generally called attenuation. Attenuation can be depicted as follows:

$$c(\lambda) = \mathrm{a}(\lambda) + b(\lambda) \tag{1}$$

Where $c(\lambda)$ is the attenuation, and λ is the light wavelength, $\mathrm{a}(\lambda)$ is absorption and $b(\lambda)$ is scattering. The attenuation of light in seawater is exponential, and the attenuation coefficient is assumed to remain constant throughout the transmission process. The received power of the laser can be obtained , the power expression is as follows:

$$P_r = P_t \times \exp[-c(\lambda) \times d] \tag{2}$$

Where P_r is the power of receiving end, and P_t is the power of transmitter, d is transmission distance. The formula (2) is a complete exponential attenuation model of the seawater channel. After long-distance transmission, it is not enough to consider the attenuation model, and the spatial expansion of the optical beam also needs to be discussed[3]. The geometric expansion model in the process of optical transmission is illustrated in Figure. 1:

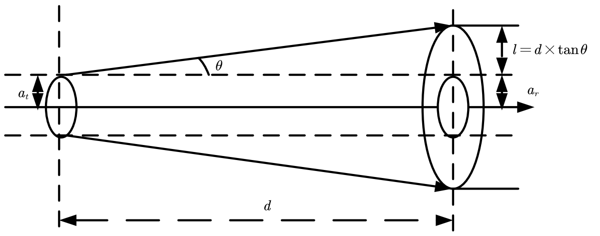

Figure. 1 Optical expansion schematic diagram

Where a_t is transmitter radius , and a_r is receiver radius, θ is optical beam dispersion angle, d is described transmission distance. According to these parameters and simple geometric principles, the light intensity area of the receiving plane can be expressed as follows:

$$S = \pi(d \times tan\theta + a_t)^2 \tag{3}$$

Geometric attenuation is determined according to the ratio of effective receiving area to spot diffusion area, so the geometric attenuation is as follows:

$$G = a_r^2/(d \times tan\theta + a_t)^2 \tag{4}$$

In simulation experiment, the gaussian beam is used, it obtain the light intensity and mathematical expression of the receiving position as follows:

$$f(x) = a \times e^{-(x-b)^2/c^2} \tag{5}$$

Where Parameter a is refers to the peak value of the Gaussian curve, b is the abscissa corresponding to the peak value, and b is the standard deviation, where it can represent the width of the spot. The complete light intensity model of the beam propagating power at the receiving point can be obtained by referring to the above formulas (2), (3) and (4), it can be expressed as follows:

$$P_s = P_t \times a \times \exp[-c(\lambda) \times d] \times G \times f(x) \tag{6}$$

The distribution relationship between receiver and spot center r can be simulated 15, 20 and 25 meters in MATLAB by using formula (6), as shown in the Figure.2:

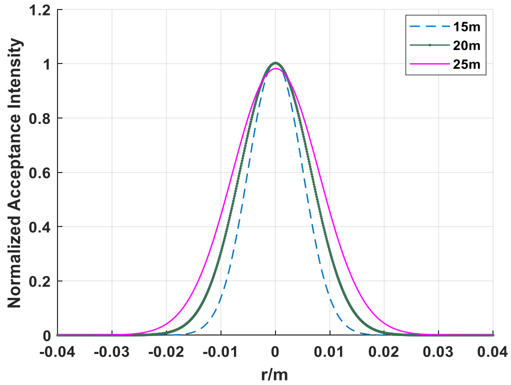

Figure.2 Normalized intensity distribution at different transmission distances

As shown in Figure 2, the farther r the receiver is from the spot center, the smaller the received light intensity, and the receiver has the maximum received power at the spot center ($r = 0$) gradient descent optimization algorithms.

In this paper proposal, the GDOA is based on the spatial distribution of light intensity[6]. To show the advantages of the gradient descent optimization algorithm, it is compared with the one-dimensional search algorithm (ODSA) in the experiment.

The idea of ODSA is simple, it uses the heuristic method, every step is decided, according to the result of the decision information. The direction of a search, and the distance to travel.

GDOA creatively introduces a variable called momentum[4], which can be understood as Momentum in physics. It can be understood as a ball falling from the top of a mountain to a valley, and the accumulated momentum makes it faster and faster because of the air resistance to make fraction $\gamma < 1$ [5]. Similarly, when the parameters are updated, the dimensional momentum in the same direction as the gradient increases and the dimensional momentum in the direction of the gradient changes decreases, thus faster convergence and less oscillation can be achieved. Through the fig.3 that the principle can know, as shown in the Figure. 3:

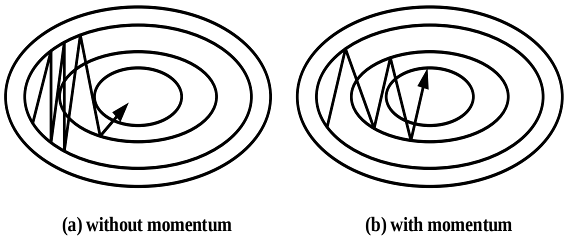

Figure. 3 GDOA schematic diagram

Figure.3 describes the difference between a search without momentum and a search with momentum. The momentum process can be seen from the search process, which with momentum has the advantage of less search times and small fluctuation.

According to the principle of gradient descent optimization algorithm and the spatial model of light intensity, the flow chart of the algorithm is designed to simulate the experiment, the flow chart as shown in Figure.4:

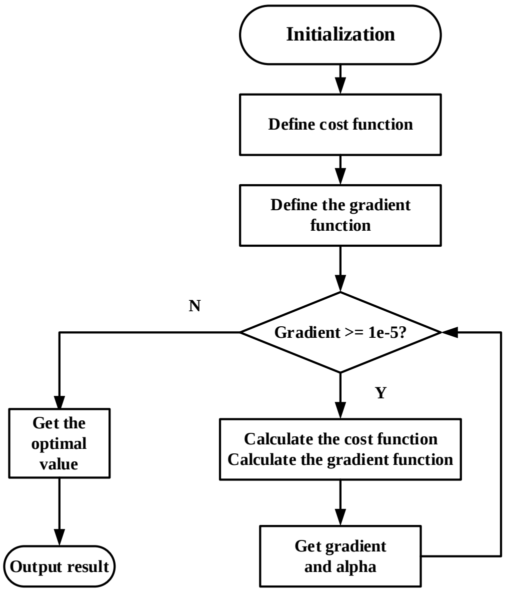

Figure. 4 GDOA program flow chart

Firstly, GDOA proceeds initialization, it abstracts the problem and presents it as a function. Secondly, the cost function and the gradient function are defined. Respectively, represent the variance between the measured value, and the actual value, and the gradient value of the updated parameter. Thirdly, the cost function and gradient function need to be calculated and get the gradient and change rate alpha. the gradient compares with $1e^{-5}$, when the gradient is less than $1e^{-5}$, it can be considered that it tends to 0 and no parameter is updated. Finally, the process is considered to have reached a maximum or minimum value.

3. Results and discussion

In this experiment, MATLAB was used for simulation analysis. It was assumed that the maximum signal voltage acceptable to the receiver was $1V$, the initial position was $r = 2cm$, the initial step was $3mm$ at distance d of 15 meters . The search would be stopped if the error of the measured voltage value was less than e^{-3}. The simulation results were shown in the Figure.5:

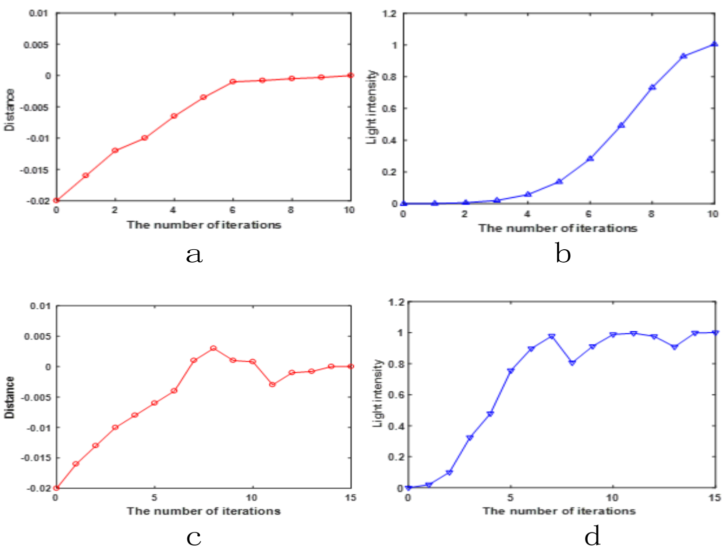

Figure.5 Numerical comparison between GDOA and ODSA

The (a) and (b) in Figure.5 used gradient descent optimization algorithm, while (c) and (d) used one-dimensional search algorithm. The curves in(a) and (c) represent the distance between the receiver and the light intensity center, (b) and (d) represent the change of light intensity with the number of iterations.

In terms of iteration times, the iteration times of GDOA are less than that of one-dimensional search algorithm (ODSA). From the data results, the alignment curve of GDOA is flat and the fluctuation degree is less than that of one-dimensional search. In summary, compared with ODSA, GDOA has the advantages of fast operation time and high accuracy.

4. Conclusion

Alignment problem in underwater optical communication is the key technology of communication system. Other researchers accepted optical signals by increasing the area of the receiver end or increasing the number of the receiver, which not only increases the cost but also the size of the receiver, it is not conducive to the miniaturization and integration of optical communication. This paper proposes for solve those problems that use GDOA to solve such problems. Compared with ODS, GDOA has the advantages of fast calculation time, good optimization effect, and high accuracy. UWOC alignment technology based on GDOA has certain practical value in the future.

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