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Development of Underwater Wireless Optical Communication

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Abstract:

Based on the development of current wireless communication technology, the development of underwater wireless optical communication technology has become a research hot spot. This paper analyzes and summarizes the development of underwater wireless optical communication technology in recent years. At present, the main underwater wireless optical communication technologies contain non-line-of-sight underwater wireless optical communication technology, high-speed underwater wireless optical communication technology, underwater wireless optical communication positioning technology. At the same time there are still some challenges in the development, which include light attenuation and scattering, choice of light sources and detectors, environmental unpredictability, energy consumption and durability, multiple-input and output technology. In this paper, these problems are systematically sorted out and analyzed and outlook the development trend of underwater optical communication technology.

Keywords: Underwater wireless optical communication; data transmission; optical channel

1. Introduction

The ocean is one of the frontier areas of concern and research, and it contains a large number of natural resources that need to be developed. The development of human society cannot be separated from the exploration of Marine resources. The terrain of the water can affect traditional underwater optical fiber communication, it cannot cover some special locations. In this case underwater wireless optical communication is a good choice. Underwater Wireless Optical Communication (UWOC) is a kind of wireless communication technology that transmits data through water through light waves. It transmits digital information by modulating the intensity and frequency of light waves such as visible light and infrared light. It has the advantages of unregulated operating frequency band and high transmission rate.

Currently, underwater wireless optical communication is faced with many challenges, mainly light attenuation and scattering, light source and detector selection, multi-path propagation, environmental unpredictability, energy consumption and durability, multi-input and output technology. This paper summarizes the research progress of UWOC at home and abroad. Including UWOC dynamic threshold decision technology, adaptive array technology in UWOC system, non-line-of-view UWOC technology, high-speed UWOC technology. These technologies can make UWOC have a broader development space in the future.

This paper first introduces the types and research status of UWOC systems and expounds the principles and applications of several common UWOC technologies. This study analyzes the innovation of this technology and its contributions in the scientific field and summarizes the current limitations of these technologies as well as their future development and application space.

2. Overview of Mainstream Technology of Underwater Wireless Optical Communication

2.1 Dynamic Threshold Decision Technique for Underwater Wireless Optical Communication

The main interference of optical signal in underwater channel transmission includes absorption, scattering, turbulence and noise, which will make the optical signal power attenuation and random shake, and then produce serious code distortion. The fixed threshold decision scheme will produce a bit error rate (BER) threshold phenomenon, while the dynamic threshold decision scheme not only can effectively improve the signal-to-noise ratio performance of the UWOC system, but also control the generation of BER threshold.

Zhenghui Wang, determined the dynamic threshold for UWOC system using MI-DD scheme based on the characteristics of slow fading of underwater turbulence channel [1-3]. The simulation results show that the error performance of the dynamic threshold decision scheme is 5.4dB higher than that of the fixed threshold decision scheme when the BER of the system is 10^{-6} in the weakly turbulent channel environment. In the medium turbulent channel environment, the BER of the fixed threshold decision scheme will not decrease with the increase of the SNR when the SNR is larger than 35dB, while the BER of the dynamic threshold decision scheme will decrease significantly. The error performance of the dynamic threshold decision technology will increase by 5.3dB when the BER is 10^{-6}. Under strong turbulence conditions, the error rate threshold of the fixed threshold decision technique appears at 20dB, while the dynamic threshold decision technique has an increase of 8.6dB [3]. This scheme has the characteristics of low computational complexity and easy implementation in real-time communication system and has important engineering application value in UWOC system.

2.2 Non-Line-of-Sight Underwater Wireless Optical Communication

At present, line-of-sight communication is the main method used in UWOC systems studied at home and abroad. However, it has higher requirements for acquisition alignment tracking, and it is easy to interrupt communication when there are obstacles. Therefore, the researchers proposed non-line-of-sight UWOC mode, that is, the signal can be transmitted by reflection, scattering and other ways to bypass obstacles. The reflection is the reflection of light on the sea-air interface or reflect the light by the buoy which is placed on the surface of water. Scattering is the non-line-of-sight transmission of light by means of the scattering of light by particles in seawater. At present, non-line-of-sight UWOC is mainly studied by Monte Carlo simulation method [4-6]. However, this technology is not mature at present. In the actual environment, many factors will interfere with the signal of non-line-of-sight underwater wireless optical communication, especially the impact of fluctuating water surface on the BER of the communication system. The greater the fluctuation of water surface, the more obvious the impact [7].

2.3 High-Speed Underwater Wireless Optical Communication

High-speed UWOC technology which uses light waves (usually laser or LED light source) to transmit data in the underwater environment. High bandwidth and high speed are the greatest advantages, and this technology is a powerful supplement to traditional underwater acoustic communication technology. The high-speed UWOC system is generally consisted of three parts: the launching system, the receiving system and the underwater channel. The OOK modulation technology can realize high-speed data transmission and improve the error performance of the system at the same time. The sliding window average filtering method can be used to remove the noise in the received data, and the combined threshold value can be obtained according to the fixed threshold value and adaptive threshold value, and then the threshold judgment can be carried out [8]. High-speed UWOC technology based on signal processing has lower cost and higher efficiency [9]. Fig.1 shows the composition of a high-speed UWOC system [10].

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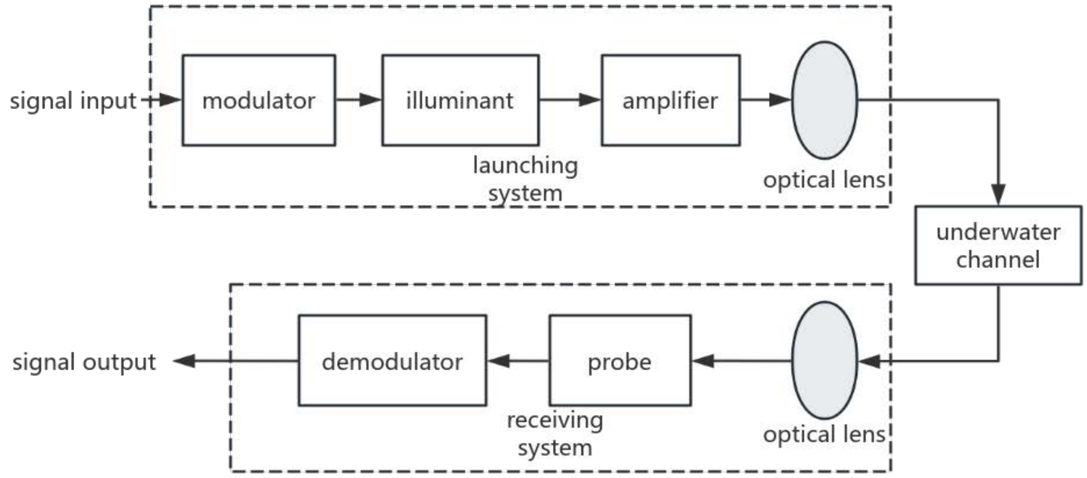

Fig. 1 High-speed UWOC system structure diagram

Signal processing technology can be divided into two categories: modulation technology and equalization technology. The transmission rate of modulation technology is higher, and the signal bandwidth of equalization technology is larger [10]. Researchers from the Japan Marine Earth Science and Technology Agency (JAMSTEC) and Trimatiz Ltd. have successfully developed and tested an UWOC system capable of achieving a data transmission rate of 1Gbps over a distance of 100 meters[11]. The key to this progress is the use of laser communication instead of sound waves, which enables longer communication distances underwater and higher data rates [11].

2.4 Adaptive Array Technology for Underwater Wireless Optical Communication

In the receiver array system of underwater wireless optical communication, the underwater channel and receiver noise affect the signal processing of the system, especially the turbulence change in the optical channel and the randomness of the detector quantum noise bring great difficulties to the subsequent array signal processing. An adaptive array merging algorithm that is easy to be implemented by hardware is proposed by Juhuo Jiang, who aimed at the uneven distribution of light intensity on the array caused by turbulence changes to improve the communication performance of the array system [12].

Adaptive array technology uses multiple antennas to receive signals and adjusts the weighted coefficients of each antenna by algorithms to optimize the quality of the received signals. Taking Avalanche Photo Detector (APD) and PIN photodiode as research objects, the receiving end of underwater optical wireless communication can use array receiver to improve communication performance [12]. At the receiving end, an array receiver can not only increase the receiving field of view Angle and receive complete signals by the diversity of multiple detectors, but also combine and enhance signals by appropriate array detection methods and adaptive array merging algorithms, so that the receiver can receive optical signals of sufficient intensity and reduce the influence of background radiation, which is very suitable for detecting weak signals [12]. It plays a very important role in military, Marine resources development, environmental monitoring and other fields.

2.5 Underwater Wireless Optical Communication Positioning Technology

Sensor node positioning technology in UWOC is an effective way to promote the accuracy of UWOC systems, and it is a essential condition for data labeling, target detection and tracking. Positioning methods can be roughly divided into four categories: distance measurement, information calculation location, network scale and anchor utilization [13].

At present, the positioning technology based on UWOC is not mature, and related technologies are still in the early stage of development, and there are mainly the following technologies. Based on the idea that an acoustic link is used for NLOS positioning and the optical link is used for LOS transmission, a hybrid acousti-optic target positioning and tracking scheme for different links is proposed to achieve accurate underwater positioning, moving target tracking and high-rate data transmission [14]. A node mobility model and deployment algorithm are proposed to address the constrained mobile sensor node location problem in UWOC network, but only LOS link communication is considered, not NLOS link communication [15]. The relevant research team in China proposed and partially realized a UWOC module scheme integrating the ranging method and two-dimensional positioning algorithm, using photo-electricity diodes for distance estimation, and calculating the two-dimensional relative position of nodes through the detected photo-electricity diode light signal strength. This scheme has largely solved the difficulties in the intricate underwater environment. The positioning accuracy was improved [16].

3. Challenges and Outlooks

At present, the UWOC system has had a relatively mature development, but there are still many challenges. When the Monte Carlo simulation method is used to simulate the sea as a uniform and static medium, it is inconsistent with the actual uneven and dynamic sea, and there are errors [4]. UWOC positioning technology still has many problems, including mobile node positioning problems, low positioning coverage, limited energy [13]. The mobile node location problem is the most critical. Due to the influence of underwater turbulence and aquatic biological activities, the optical sensor nodes deployed underwater will move irregularly with ocean currents and deviate from the original ideal position, which will bring great challenges to UWOC positioning [13]. For the positioning of mobile nodes, there are relatively few existing node movement models, most of which take the ocean current movement model [17-18] as the node movement model, while there are few node movement models for anchor nodes and unknown nodes respectively, which will bring great deviation to the positioning. In the adaptive array technology of UWOC, the delay expansion characteristic of the optical signal in the channel is not considered [12].

As a widely used and high-performance communication technology, underwater wireless optical communication will develop in the following aspects in the future: transmission rate and transmission distance will be improved, enhance anti-interference ability, expand application scenarios, reduce cost, power consumption. With the development of 6G technology and the increasing demand for integrated air, air and Haiti communication networks, people will pay more and more attention on underwater wireless optical communication.

4. Conclusion

Based on the analyze of UWOC, this paper compares and analyzes the breakthroughs and applications of various UWOC technologies. Firstly, the technical problems of underwater wireless optical communication are discussed, such as attenuation caused by light scattering and absorption in water, energy consumption, and multi-path propagation. Then, this paper introduces and summarizes several key UWOC technologies.

Future UWOC technology can achieve further breakthroughs in the special complex underwater environment. At the same time with the progress of communication technology and the blessing of the progress of artificial intelligence, UWOC technology has great potential for development, and will also play an increasingly important role in people's production and life.

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