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Underwater Optical Wireless Communication Link Capability in Deep Ocean Communication

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ABSTRACT

In this paper, we propose new oceanographic observation. The Seafloor Observatory Network has the advantages of long distribution distance and wide coverage. The use of autonomous underwater vehicles (AUVs) is highly desirable for collecting data from seafloor sensor platforms within a close range. With the recent innovations in underwater wireless optical communication (UWOC) for deep-sea exploration, UWOC could be used in conjunction with AUVs for high-speed data uploads near the surface. In addition to absorption and scattering effects, UWOC undergoes scintillation induced by temperature- and salinity-related turbulence. However, studies on scintillation have been limited to emulating channels with uniform temperature and salinity gradients, rather than incorporating the effects of turbulent motion. Such turbulent flow results in an ocean mixing process that degrades optical communication. This study presents a turbulent model for investigating the impact of vehicle-motion-induced turbulence via the turbulent kinetic energy dissipation rate. This scintillation-related parameter offers a representation of the change in the refractive index (RI) due to the turbulent flow and ocean mixing. Monte Carlo simulations are carried out to validate the impact of turbulent flow on optical scintillation.

Index Terms— autonomous underwater vehicles; underwater optical communication; ocean mixing; scintillation

I. INTRODUCTION

Underwater acoustic communication is a technique of sending and receiving messages below water. There are several ways of employing such communication but the most common is by using hydrophones. Underwater communication is difficult due to factors such as multi-path propagation, time variations of the channel, small available bandwidth and strong signal attenuation, especially over long ranges. Compared to terrestrial communication, underwater communication has low data rates because it uses acoustic waves instead of electromagnetic waves.

In general the modulation methods developed for radio communications can be adapted for underwater acoustic communications (UAC). However some of the modulation schemes are more suited to the unique underwater acoustic communication channel than others. Underwater Sound With The Water, Its Contents And Its Boundaries. The Water May Be In The Ocean, A Lake, A River Or A Tank. Typical Frequencies Associated With Underwater Acoustics Are Between 10 Hz And 1 MHz. The Propagation Of Sound In The Ocean At Frequencies Lower Than 10 Hz Is Usually Not Possible Without Penetrating Deep Into The Seabed, Whereas Frequencies Above 1 MHz Are Rarely Used Because They Are Absorbed Very Quickly. Orthogonal frequency-division multiplexing(OFDM) is a digital multi-carrier modulation scheme. OFDM conveys data on several parallel data channel by incorporating closely spaced orthogonal sub-carrier signals OFDM is a favorable communication scheme in underwater acoustic communications thanks to its resilience against frequency selective channels with long delay spreads.

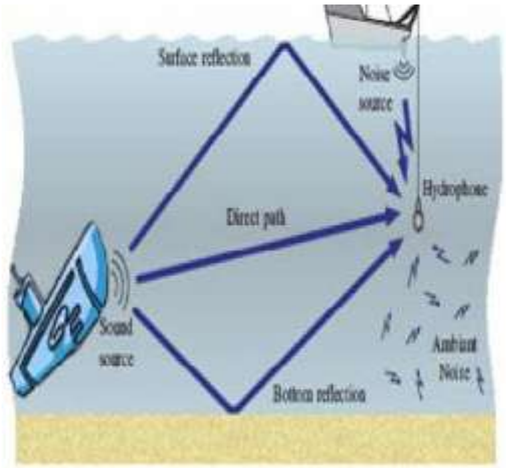

Fig 1: Data communication in seawater

Optical signal propagation through underwater channels is affected by three main degrading phenomena, namely absorption, scattering, and fading. In this paper, we simulates the study of statistical distribution of intensity fluctuations in underwater wireless optical channels with random temperature and salinity variations as well as the presence of signal to noise ratio.

II. MODEL OF TURBULENCE-INDUCED SCINTILLATION

Optical Scintillation

The underwater communication links experience intensity fluctuation when the optical wave propagates through the Seawater medium due to the change in the RI along the propagation path. The inhomogeneous RI distribution can be caused by the inhomogeneous thermohaline distribution in seawater. The change in thermohaline characteristics at different depths has been shown in the ocean profile data provided by the world ocean database [20] in Fig. 2. In deep water (> 1500 m deep), the gradients of temperature and salinity were < 1 °C per kilometer and ~0.2 part-per-thousand (ppt) per kilometer, respectively. Quantifying the intensity fluctuations in the thermohaline environment is required before optical channel characterization.

Simulation Results

In this paper, we focus on presenting a simple physical simulation model based on Monte Carlo method for a turbulent UWOC horizontal link. The Monte Carlo algorithm is far less computationally intensive compared to the approaches based on computational fluid dynamics.

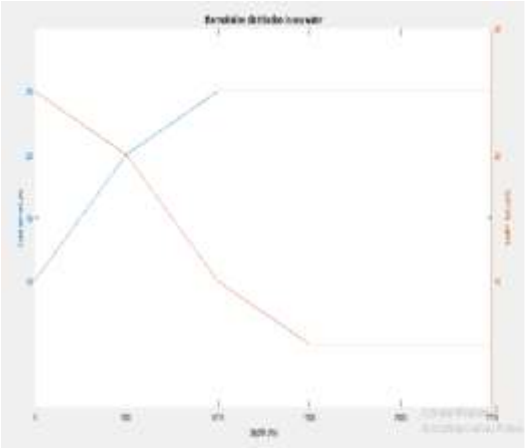

Fig. 2: The temperature and salinity of seawater

The proposed model is based on the interaction of propagating photons with a turbulent medium, which is presented in consecutive turbulent cells with different RI, denoted as ni. Each turbulent cell is a unit of seawater medium in which the optical signal propagates. The ni depends on the temperature of water, T, salinity of water, S, and wavelength of the light, λ.

The received intensity of optical signal is calculated based on the fraction of received photons to the transmitted photons. The propagation path of each simulated photon from the transmitter is mainly dependent on the changes of ni. The photon is assumed to move in a straight line until it reaches the boundary of the following cell.

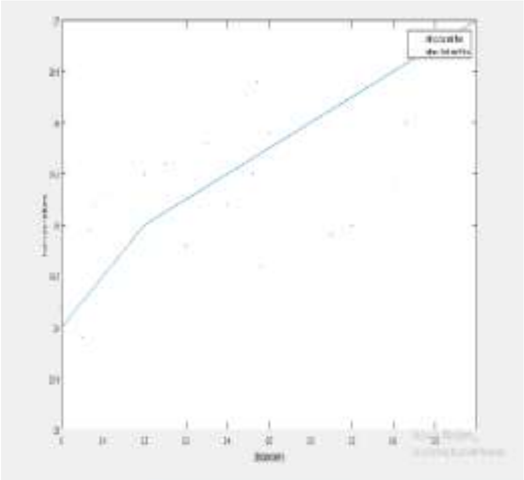

Fig 3: Temperature Gradient (°C/m)

III. RESULTS AND DISCUSSION

The simulation output was conducted under a uniform temperature condition. To create the temperature gradient, we set the temperature on the transmitter's side to the lowest temperature in the gradient with each successive layer having a slightly higher temperature until the maximum value is reached on the receiver's end.

However, in the case of turbulent water, the random movement is assumed to move water molecules around, creating random variations in the temperature value. The eye diagrams of the optical beam with temperature gradient are shown in Fig. 4 and Fig 5.

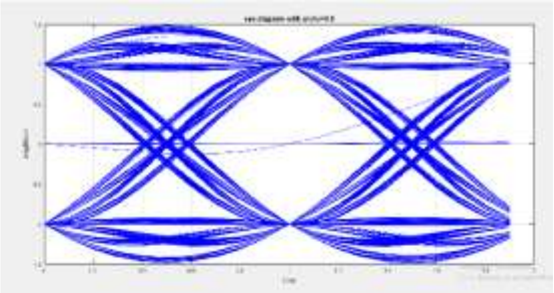

Fig 4: The eye diagram of OOK modulated optical communication in the deep ocean with temperature gradient alpha=0.5

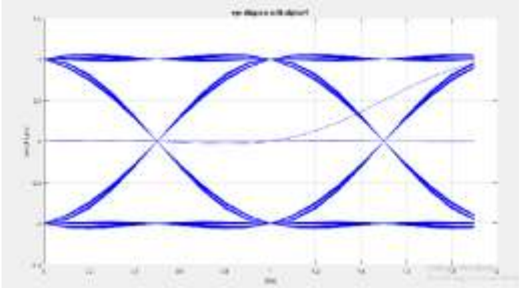

Fig 5: The eye diagram of OOK modulated optical communication in the deep ocean with temperature gradient alpha=1

The intensity distribution and SI were recorded and presented in Fig. 6, Fig7 and Fig 8. Compared to the result of the turbulent flow-induced mixing process, the optical communication qualities without this mixing were almost the same. Thus, the turbulent flow seldom disturbs the density distribution.

According to Fig. 6, 7, 8, the dissipation rate of the temperature is extremely low if there is no temperature gradient. A temperature gradient occurs in the second diagram where the inlet water temperatures from the two circulators are set to 0.5°C and 1°C. The values in the no mixing group and mixing group differ by two orders of magnitude, which show that turbulent-flow-induced mixing contributes to scintillation.

This difference is evident in both the eye diagram and the SI. Thus, turbulent flow can seriously affect the optical pattern in the same gradient medium. The eye diagram was difficult to record because the signals vibrated frequently. As shown in Fig. 4 and Fig. 5, the amplitude was reduced by at least half of that of 0.5°C temperature gradient. In some cases, the signals in the group with the mixing process may have the same order of amplitude as noise because of the scintillation.

The SNR quantifies these results. The minimum and maximum SNR of 1°C gradient mixing group are 110 dB and 130 dB, respectively, while the corresponding SNR in 0.5°C gradient group are 80 dB and 90dB.

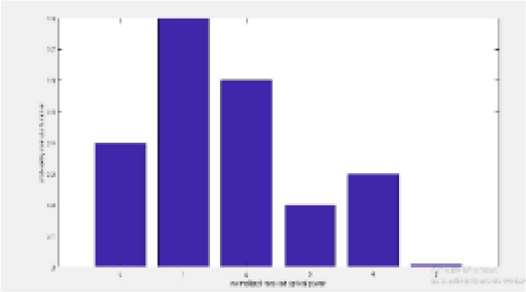

Fig 9: No temperature gradient

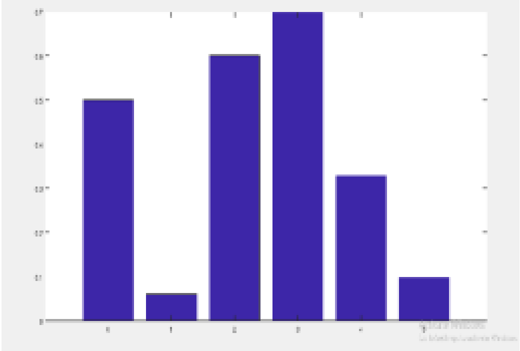

Fig 10: Temperature gradient with alpha=0.5

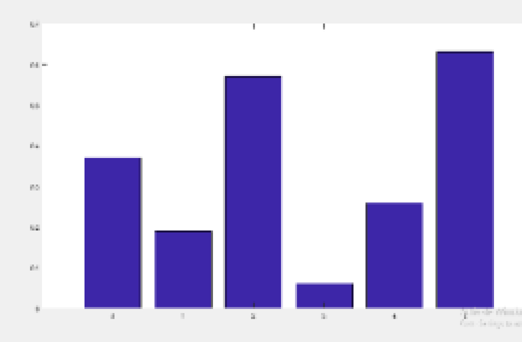

Fig 11: Temperature gradient with alpha=1

The BER and SI also reflect the poor communication quality. The measured BER was 1.2×10- 9, which can barely be corrected under current error correction codes. From the measurements, the performance degrades as the temperature gradient increases. If turbulent flow exists, the communication quality degrades further. In fact, the BER under the condition of a 0.5-°C gradient with mixing was higher than that under a 1-°C gradient without mixing.

IV. CONCLUSION

This project investigated the relationship between turbulent-flow-induced mixing process and scintillation in UWOC because communication quality is crucial when underwater vehicles equipped with wireless optical systems are used to collect data from seafloor platforms. We considered the modeling of the influence of turbulent-flow induced mixing process on scintillation of underwater optical links. The Monte Carlo based simulation was applied to verify the model. In future work on mitigation strategies, the aperture averaging technique is considered to be a potential technique for combating scintillation. This method avoids receiving waves from a single propagation path, and the averaging of identical apertures erases relatively fast fluctuations due to small turbulence. Significantly, the fading of received signals become smoother after using this technique.

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