Effects of Gaussian fading on OAM Images in High Atmospheric Turbulence

Young Jae Moon, Aye Yadanar Win, Siti Hasunah Mohammed, Marvin Molida*, Sudhanshu Arya**,
Yeon Ho Chung†
Pukyong National University, Republic of Korea, *Universidad Libre de Barranquilla, Colombia,
**Stevens Institiute of Technology, USA

† yhchung@pknu.ac.kr

강한 대기 난류에서 가우시안 페이딩이 OAM 이미지에 미치는 효과

문영제, 에이 예데나 윈, 시티 하수나 모하메드, 마빈 몰리다*, 슈단슈 아르아**, 정연호
Pukyong National University, Republic of Korea, *Universidad Libre de Barranquilla, Colombia,
**Stevens Institiute of Technology, USA

Abstract

In this paper, we introduce a scenario involving the transmission of orbital angular momentum in high atmospheric turbulence conditions. In this environment, the Laguerre-Gaussian beam's intensity image appears as a speckle field. Therefore, we examine the influence of Gaussian fading on the channel during the transmission. Then, we compare the demodulation results of Gaussian fading with those obtained under Gaussian noise conditions.

Ⅰ. Introduction

Recently, orbital angular momentum (OAM) in the field of electromagnetic (EM) waves has been attractive for high transmission speed over terahertz ranges. A helical transverse phase structure would be presented in optoelectronic systems that carry OAM, like Laguerre-Gaussian (LG) beams, as $\exp(il\phi)$ [1]. Here, ϕ represents the transverse azimuthal angle, and l is an unbounded OAM mode number. Orthogonal to one another, beams with distinct OAM values of l and p permit multiplexing along the same beam axis. Because LG beams are easy to multiplex each other with data encoded [2], learning-based methods are used to identify the OAM state in optical communication over long distances.

However, when the LG beam propagates through high atmospheric interference, the interference itself alters the toroidal phase structure of OAM, resulting in a speckle pattern. Though the random scattering is intricate, it is possible to identify the LG beam mode number by examining the connection between the input modes and the generated speckles. Nevertheless, further research is essential to comprehend its effects and to ensure a reliable transmission. Therefore, this paper introduces the effect of Gaussian fading on OAM image by analyzing channel behavior alongside demodulation results.

The simulation environment is presented in Section 2, the channel characteristics against Gaussian fading compared with Gaussian noise results are provided in Section 3, and conclusions are derived in Section 4.

Ⅱ. Simulation Model

The LG beam with a consistent OAM mode is treated as a data channel where bits '1' and '0' are denoted by the presence and absence of the beam, respectively. The electric field of the LG beam is given by

$$\vec{E} = U(r,\phi,z)\,\hat{a} \tag{1}$$

where $\hat{a}$ is a constant unit vector, and $U(r,\phi,z)$ is [3]

$$\begin{aligned} U(r,\phi,z) = \alpha r\sqrt{\frac{2p!}{\pi(p+|l|)!}}\left(\frac{1}{w(z)}\right)^{|l|+1} \\ \times L_p^{|l|}\left(\frac{2r^2}{w^2(z)}\right)\exp\left[\left(-1-j\frac{z}{z_R}\right)\left(\frac{r}{w(z)}\right)^2\right] \\ \times\exp[-i((|l|+2p+1)\psi(z)+l\phi+kz)] \end{aligned} \tag{2}$$

where α is a constant, z is propagation distance, $w(z)$ is the beam radius, LG_p^l is the associated LG beam with Laguerre polynomial with transverse mode p and angular mode l, k is the optical wave number and z_R is the Rayleigh range.

However, as LG beams propagate through more highly dense media, the size of the speckle decreases, and its pattern becomes more uniform as the topological charge increases [4]. Consequently, OAM image uniformity makes it harder to distinguish the beam mode, such as a LG beam speckle, Fig. 1, shows a speckle image when the LG beam wavelength is 1550nm and l is 1.

We consider a Laguerre-Gaussian transmission model characterized by high-density atmospheric turbulence in the propagation process. Subsequently, we investigate the Gaussian fading impact on an OAM speckle through a channel behavior examination, while conjugating the results with the modulation-demodulation process when Gaussian noise is incorporated.

Ⅲ. Results

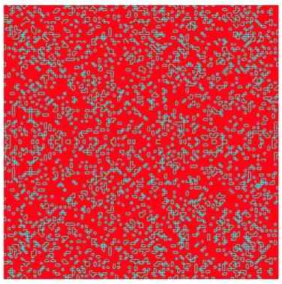

Fig. 1. Speckle Image of the LG beam

As in Section 2, we transmitted the original OAM image as presented in (a) of Fig. 2 and Fig. 3 through Gaussian fading and Gaussian noise, respectively. The modulated result with Gaussian fading in Fig. 2. (b) indicates that the modulation made a darker color shift. However, it shows a similar speckle size and shape to the original.

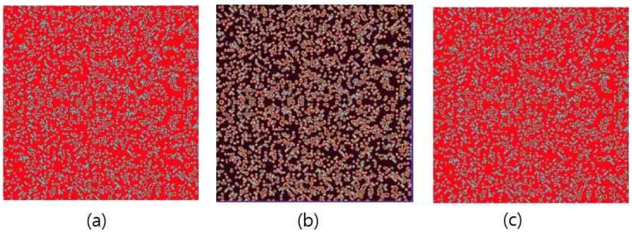

Fig. 2. Modulation result with Gaussian fading

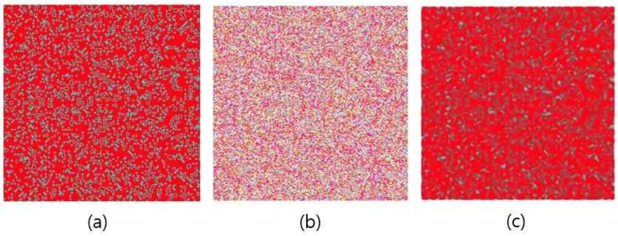

Fig. 3. Modulation result with Gaussian noise

After applying a 0.5 ratio Rayleigh filter to demodulate the modulated image, the resulting demodulated OAM image in Fig. 2 (c) was able to be decoded with a high success rate of 97%. However, when a median filter was applied to the demodulated OAM image in Fig. 3 (c), affected by Gaussian noise, the resulting image was blurry and only had an 89% decoding capability. This indicates that the speckled image is much stronger under Gaussian fading than under Gaussian noise.

Ⅳ. Conclusions

We have modulated the Gaussian fading when the LG beam is propagating high-density atmospheric turbulence (AT), generating a speckle-like image. While investigating the channel characteristics, we have also presented the decoding rate as the modulated speckle image was demodulated when 0.5 ratio of Rayleigh noise was applied. Throughout this process, we can achieve a 97% rate of recovering the original mode and the encoded data. Our ultimate goal is to look into approaches that will use OAM communications with a convolutional neural network in future studies for creating a realistic free space optical transmission environment.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korean government (MSIT) (2023 R1A2C2006860).

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