Vortex Beam Generation Method based on Spatial Light Modulator

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Abstract. Aiming at the problem that the vortex beam is difficult to obtain under laboratory conditions, a vortex beam generation method based on spatial light modulator (SLM) is proposed. The collimated laser beam is modulated into a vortex beam by uploading a spiral phase mask attached to a grating on a SLM. Simulation results verify the effectiveness of the proposed method. The beam obtained from the experimental results also conforms to the properties of the vortex beam.

1. Introduction

In 1979, Vaughan [1] found that the phase structure has a certain specialty in the research work on the vortex beam. Since Coullet [2] et al. first proposed the concept of vortex beam in 1989, the vortex beam has attracted wide attention from researchers because of its high concentration and spiral phase. The application of a variety of vortex beams has been proposed. For example, optical encryption based on vortex beam [3], information coding based on vortex beam [4], optical tweezers based on vortex beam [5,6].

In order to obtain the vortex beam more conveniently, a method for generating a vortex beam by using a spatial light modulator is designed. The collimated laser beam is modulated into a vortex beam by uploading a spiral phase template on a SLM attached to a grating splitting. Further numerical simulations and experiments validate the effectiveness of the method proposed.

2. Vortex Beam

The vortex beam is a type of beam with an isochronous surface that has a helical angular momentum. During the transmission process, the center of the beam is singular due to phase uncertainty or sudden change. The intensity at the singular point is zero, no heating effect, no diffraction effect.

The vortex beam has a helical phase-distributed beam with a phase factor \( \exp(-i\ell \varphi) \) in its expression, and each photon in the beam carries \( \hbar \ell \) orbital angular momentum, where \( \ell \) is the topological charge.

The orbital angular momentum of the vortex beam determines that the photon will transmit the angular momentum carried by the photon to the particle during the interaction with the particle, causing the angular deflection of the particle, thereby realizing the manipulation of the particle rotation. That is the optical tweezers.
3. Simulation

The numerical simulation of the generation of the vortex beam of the topological charge $l=1$, $l=3$, $l=10$, $l=30$ and respectively is carried out. The laser wavelength was 632.8 nm and the diffraction distance was 400 mm. The object surface is $100 \times 100$ -pixel. The image surface is $200 \times 200$-pixel. The radius of the spiral phase mask is 10mm. Each pixel is $8 \text{um}$.

The phase function of the vortex beam is as shown in Formula (1).

$$t(\theta) = \text{angle}\{\exp[-il\theta]\} + \pi$$  \hspace{1cm} (1)

The spiral phase templates generated by Formula(1) with the topological charge of $l=1$, $l=3$, $l=10$, $l=30$ are shown in Figures 1(a) to (d), respectively.

![Spiral phase templates](image)

**Figure 1.** Spiral phase templates: (a) $l=1$, (b) $l=3$, (c) $l=10$, (d) $l=30$.

Taking the spiral phase mask shown in Fig. 1 (b) as an example, the plane wave is vertically incident on the spiral phase mask to obtain a vortex beam, and the complex amplitude of the light field is calculated by the Fresnel diffraction integral formula shown in Formula (2) at the diffraction distance $z=400$. The complex amplitude distribution of the field. The simulation results are shown in Figure 2.

$$E(x, y) = \frac{\exp(ikz)}{i\lambda z} \iint E(x_i, y_i) \exp\left\{\frac{ik}{2z}[(x-x_i)^2 + (y-y_i)^2]\right\} dx_i dy_i$$  \hspace{1cm} (2)
Figure 2. Vortex beam simulation results of $l=3$: (a, c, and d) amplitude of the vortex beam (b) phase of the vortex beam (the axes in the figure are all pixels).

4. An Optical Experiment To Validate The Scheme
In order to further verify the feasibility of using SLM to generate vortex beams, an optical experimental system was built for experimental research. The experimental system is shown in Figure 3. The He-Ne laser has a wavelength of 632.8 nm, and the spatial light modulator uses Holoeye PLUTO-VIS-014. The SLM has 1920×1080 pixels with spans of 8μm. The CCD has 768×576 pixels with spans of 8.3μm.

Figure 3. The experimental system: (a)schematic diagram of the experimental system, (b) photograph of the experimental system. (1) He-Ne gas laser, (2) attenuator, (3) spatial filter, (4) aperture, (5) lens, (6,7, and 9) polarizers, (8) SLM, (10) CCD.

In the experiment, the spiral phase masks of the topological charge $l=1$, $l=3$, $l=10$, $l=30$ are uploaded on the SLM. For ease of observation, a grating is attached to the spiral phase mask for light
splitting. After the collimated laser beam is modulated by the SLM, the vortex beams collected by CCD are shown in Fig. 4.

By comparing Fig. 4(a) to (d), it can be seen that as the topological charge increases, the central singularity increases continuously, which is one of the important properties of the vortex beam.

![Figure 4](image)

**Figure 4.** Vortex beams with different topological charge number \( l \).

The vortex beam acquired by the CCD at different diffraction distances \( z \) is shown in Fig. 5.

![Figure 5](image)

**Figure 5.** Vortex beams with different diffraction distances \( z \).

5. **Conclusion**

Aiming at the problem that the vortex beam is difficult to obtain under laboratory conditions, this paper proposes a method for generating a vortex beam by using a SLM. The method realizes the generation of the vortex beam by transforming the collimated laser beam into a vortex beam by uploading a spiral phase template attached to a grating on the SLM. Simulation and experimental results verify the effectiveness of the method proposed.

**References**

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