Optical vortex pair detection using a triangle aperture

Dina Grace C. Banguilan*, Nathaniel P. Hermosa II

National Institute of Physics, College of Science, University of the Philippines, Diliman, Quezon City, 1101 Philippines
E-mail: *banguilandinagrace@gmail.com

An optical vortex (OV) exists when the real and imaginary parts of a complex electromagnetic wave field become zero, and the phase becomes singular at the beam's center [1]. The light around a beam containing OVs carries a topological charge (TC) \( \ell \) [2]. However, higher-order OVs (HOOVs) occurring in physical systems are structurally unstable [3]. An incident \( \ell \)-charged HOOV may decompose into \(|\ell|\) single-charged OVs by conservation of topological charges. Due to their instability, OVs may appear at random locations within the host background. Here, we detect an optical vortex pair (two single charged OVs in a single beam) using the diffraction of light by a triangular aperture.

We consider a vortex mode \( U_\ell(r, w) \) with a total TC \( \ell \): 
\[
U_\ell(r, w) = \prod_{i=1}^{N\ell} A(r, w) r^{\ell_i} \exp(i\ell_i \phi_i) 
\]
with \( \phi_i = \tan^{-1}\left(\frac{y-y_i}{x-x_i}\right) \) and \((x_i, y_i)\) is the vortex' position and \( \ell_i \) is the \( i \)-th vortex' TC. In equation (1), we embed an isopolar \((\ell_1 = +1, \ell_2 = +1)\) and bipolar \((\ell_1 = +1, \ell_2 = -1)\) vortex pair in a Gaussian background \( A(r, w) \). We place the pair symmetrically about the beam center such that \((x_{\ell_1}, y_{\ell_1}) = (-x_0, 0)\) and \((x_{\ell_2}, y_{\ell_2}) = (+x_0, 0)\) and \( d = 2|x_0| \).

We detect a vortex pair using a scanning triangle aperture whose central position \( x_0 \) can be displaced and whose \( r \) can be varied. When \( x_0 = 0 \), the aperture is coaxial with the beam. Thus, when \( d = 0 \) separates the vortex pair, and we place the aperture at \( x_0 = 0 \), the diffraction consists of bright lobes and has either a dark or bright core, see Figure 1(c)-1(e). An OV appears at minimum intensity regions; hence, the power at the pattern's center can represent a vortex position. We use a pinhole to measure the intensity at the pattern's center, whose size is controlled according to [4].

We present in Figure 2 the central intensity of the pattern we observe at \( x_0 = 0 \). At \( d = 0 \), we have a single OV at the beam center. We expect a high central intensity region for a bipolar pair since \( \ell = \ell_1 + \ell_2 = 0 \), whereas a low central intensity for isopolar pair since \( \ell = 2 \). However, with a pair separated by \( d \neq 0 \), the intensity varies depending on \( r \). For a large aperture \( r > d \), the vortices are enclosed by the aperture. The central intensity transitions from high to low intensity for bipolar and from low to high-intensity value for the isopolar pair. With these, we can differentiate an isopolar from a bipolar vortex pair in this region. However, for a small aperture, \( r < d \), the intensity increases until it reaches a maximum value for both cases. In this region, isopolar and bipolar pairs are hardly distinguishable. But when \( r < d \), individual vortices may be traced by observing the diffraction patterns by the scanning triangle.

In conclusion, we can detect a vortex pair by measuring the central intensity of the pattern resulted from its diffraction by a triangle aperture. We locate an isopolar pair (bipolar pair) when the central intensity of the pattern observed at \( x_0 = 0 \) transitions from low to high (high to low) for \( d/r < 1 \). However, we hardly distinguish between isopolar and bipolar vortex pair at ratio \( d/r > 1 \). Nonetheless, in this region, individual vortices may be traced by observing the diffraction patterns by the scanning triangle.

Acknowledgements

D.G.C. Banguilan is a scholar of the Department of Science and Technology thru its Accelerated Science and Technology Human Resource Development Program.

References