Customization of vectorial light fields in 3d space

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Abstract: We present the customization of complex vectorial light field in three-dimensional (3d) space based on self-similar, non-diffraction and even self-imaging light fields. Our designed holographic approach enables a dynamic modulation of various degrees of freedom of vectorial fields in all three spatial dimensions. Introducing not yet known classes of vector beams, we demonstrate the transfer of characteristic scalar properties to tailored vectorial fields.

The advancement of structured light techniques has enabled a wide range of different light fields specifically tailored for chosen applications. Shaping amplitude and phase revolutionized e.g. optical tweezing or imaging techniques where orbital angular momentum (OAM) carrying fields allow for orbiting particles or reducing the spot size by STED microscopy [1]. Opening further perspectives, also the polarization of light is a degree of freedom that has recently been considered for sculpting light. Here, numerous patterns have been realized, enabling e.g. focusing to a tighter spot or giving new insights into singular optics [2].

Still, most of these polarization-structured light fields are shaped in the two-dimensional (2d) transverse plane. These 2d structured field already reveal striking properties in 2d +1 space, i.e. upon propagation, as polarization singularity explosions [3]. However, customization in 2d does not offer the option to on-demand modulate the 3d structure of a light field and all its degrees of freedom. In our contribution, we present a novel holographic approach to customize vectorial light fields fully in 3d space, embedding structured polarization in transversal as well as longitudinal space directions. Our far reaching concept is based on 3d structured scalar beams as carriers for the resulting polarization structure. Especially, our choice of different bases allows transferring scalar field properties onto the polarization configuration.

On the one hand, we demonstrate using discrete non-diffracting beams as a basis providing propagation invariant transverse amplitude and phase structures and self-healing properties. On the other hand, self-imaging light fields [4] are implemented which replicates their transverse structure including embedded optical singularities after a certain distance *d* of propagation (see Fig. 1). This self-imaging distance depends on the beam's wavelength and the composition of spatial frequencies involved. For customizing 3d structured vectorial fields, we combine these different bases with structured polarization by holographic far-field construction in such a way that we realize non-diffracting or self-imaging polarization configurations. We demonstrate the general adaption of arbitrary scalar 3d field properties and reveal the complex polarization singularity propagation dynamics of these light fields in 3d space. As an alternative approach, we exploit self-similar Laguerre-Gaussian (LG) beams for the formation of vectorial fields sculpted in 3d. It is based on counter-propagation of two or more LG fields, enabling 3d fields structured at the nano-scale.

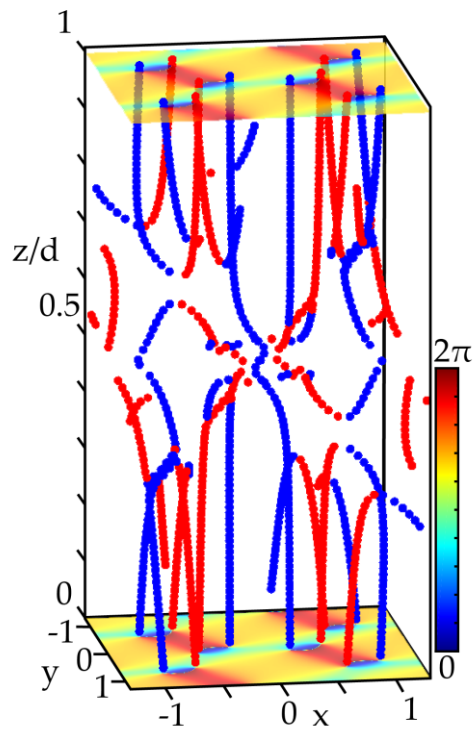

Figure 1: Propagation dynamics of positive (blue) and negative (red) indexed singularities in stokesfield $\Phi_{12} = S_1 + \mathrm{i}S_2$ of a vectorial self-imaging light field.

Overall, by shaping vectorial light field transversely as well as longitudinally, i.e. in all three spatial dimensions, we propose novel classes of vectorial fields being highly attractive for 3d optical trapping or polarization-sensitive material machining that require subdiffractive nano-scale polarization structures.

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