Coordinate nanometrology of coronavirus-like nanoparticle with topologically structured light

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Abstract: Scattering by a subwavelength particle in a structured light field containing phase singularities is highly sensitive to the particle's position. Artificial intelligence-enabled analysis of superoscillatory light field scattering, at a wavelength of 490 nm, provides for experimental determination of the 3D position of 100 nm polystyrene spheres with nanometric accuracy.

Complex coherent optical fields can contain highly localized intensity hotspots, phase singularities, zones of energy backflow and high gradients of phase at dimensional scales that can be orders of magnitude smaller than the wavelength of light. Such topologically structured fields can be generated by precise interference of multiple waves diffracted on purposely designed intensity and phase masks, and we have recently demonstrated that they can be used in "optical ruler" metrology of mutual position between macroscopic objects with nanometric precision [1].

Here, we show that topological light fields can be used to measure the position of a subwavelength nanoparticle in three dimensions via an analysis of the particle's scattering intensity patterns at few wavelength from the focal plane. Our approach exploits the significant changes in the scattering patterns that arise when the subwavelength object interacts with rapid spatial variations of the incident topological field. A deep learning process with a neural network trained on *a-priori* known positions of a nanoparticle is used to analyse scattering patterns for the determination of unknown particle positions.

Using grayscale intensity and phase masks to create a topologically structured superoscillatory light field at a wavelength λ = 490 nm, we experimentally demonstrate 3D positional measurements for 100 nm spherical polystyrene particles – representing, by size and organic polymer composition, coronavirus particles (Fig. 1a) – on a glass substrate. The discrepancy between retrieval given by the neural network and actual positions of the nanoparticle is shown in Fig. 1b, where each red dot indicates the absolute value of the 3D difference between retrieval and truth in 30 randomly selected positions. In about 900 measurements, we achieve standard deviations between actual and retrieved positions of order 5 nm (λ/100) in the *x/y* directions, and ~25 nm (~λ/20) in the light propagation direction (*z*).

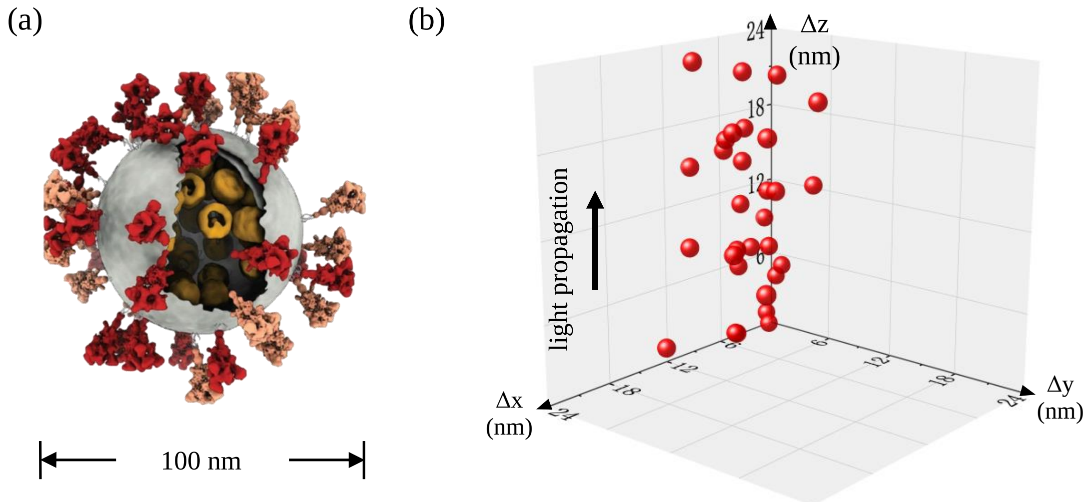

Fig. 1 (a) Artistic impression of a coronavirus with a typical size of ~100 nm, which is substituted by a polystyrene sphere in our experiment. (b) The positional errors in 30 optical measurements of the 3D coordinates of a coronavirus-like nanoparticle – a 100 nm polystyrene sphere – on a glass substrate, where each red dot indicates the absolute value of the difference between retrieved and true position of the nanoparticle. Incident light propagates along the *z*-axis.

References

[1] **G. Yuan and N. I. Zheludev,** "Detecting nanometric displacements with optical ruler metrology", Science 364, 771-775 (2019)