Dielectric Metasurfaces Generate Stable Tractor Beams

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It is well-known that light exerts a force on matter, which has proven to be useful for a myriad of applications including: manipulating and assembling nanostructures, and sorting bacteria and viruses. Propagation invariant beams are particularly well-suited for simultaneously trapping and aligning multiple particles. These beams usually exert a positive radiation pressure on an object, which pushes particles away from the source. However, it was recently shown that a net pulling force (i.e. tractor beam) can be generated if the beam is sufficiently nonparaxial (J. Chen, J. Ng, Z. Lin, C. T. Chan, Nature Photonics, 5, 531-534, 2011). The goal here is to efficiently pull a wide range of particles towards a source, independent of ambient conditions. First-order Bessel beams focus their energy toward the beam axis, which make them ideal for interacting with particles over large distances. However, no method of realizing such beams has been proposed. Furthermore, these beams have required significant damping from the surrounding fluid (i.e. viscous drag) for stable on-axis transverse trapping (N. Wang, J. Chen, L. Shiyang, Z. Lin, Phys. Rev. A., 87, 063812, 2013).

First, it will be shown that a superposition of non-diffracting TE- and TM-polarized Bessel beams of orders m=+1 and m=-1 can stably pull dielectric particles over significant distances. The beam exerts an identical pulling force as the state-of-the-art tractor beam (A. Novitsky, C.W. Qiu, A. Lavrinenko, Phys. Rev. Lett., 109, 023902, 2012), but confines the particle near the beam axis without requiring viscous damping. Thus, the proposed tractor beam can stably pull particles through vacuum, which may prove particularly useful for exploring new physics.

Next, it will be shown that the proposed tractor beam can be straightforwardly generated by illuminating a low-loss dielectric metasurface with a normally incident Gaussian beam. Specifically, we consider the case where the metasurface is illuminated with a normally incident, 1 mW Gaussian beam at a wavelength λ=1.5 μm. Full-wave simulations with ANSYS HFSS demonstrate that the transmitted beam is able to pull a polystyrene microsphere a distance of 5λ, which is equal to the nondiffracting range of the transmitted Bessel beam.