Eigenmode structured illumination for optical micro-manipulation

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Optical micromanipulation and trapping of micro-particles in vacuum promises to deliver a mechanical system that is mostly isolated from its environment ideal for mesoscopic quantum mechanics. In this area, the field of cavity optomechanics is promising new insights into the interplay between optics and quantum physics. As such, there has been a drive for quantum state preparation such as reaching the ground state of the centre of mass of mesoscopic objects. To reach this regime, the coupling between objects and their thermal environments must be minimized limiting thus the decoherence of the system. In this context, an optically trapped particle in vacuum is an ideal system for investigating quantum effects in a mechanical system, due to its near-perfect isolation from the thermal environment. These trapped particles can be stabilised and cooled via different approaches such as active feedback or passive gyroscopic effects. In both cases, the optical properties of the trapping beam are important. Indeed, different beams are associated with different trap stiffness and stabilisation properties, which can be calculated by determining the scattered field corresponding to each beam. For spherical particles, the scattered field can be described using the Lorenz-Mie theory, which makes use of vector spherical harmonic solutions of Maxwell's equations to represent the fields involved. Using these solutions it is possible to describe the light field scattered from microscopic spherical particles and thus represent the field around a scattering object as a function of the incident fields. These solutions also allow us to determine the optical momentum transfer to the scattering object by evaluating Maxwell's stress tensor.

One method to determine the optimal beam profile for optical micromanipulation is through the use of the optical eigenmode approach. Here, we use this approach together with the Mie scattering formalism to describe the quadratic relationship between the incident field and the optical forces acting on the scattering objects. This allows the introduction of solutions of Maxwell's equation corresponding to orthogonal structured illuminations, which can be ordered by optical trapping efficiency, for example. The orthogonal eigenmode with the largest trapping efficiency will then correspond to the optimal beam for the optical system considered. These optimal beams can then be used to design and optimise nanophotonic devices, such meta-surfaces, which enhance the coupling between the incident light field and these optimal beams.