Implementation of scattering of generalized Bessel beams in the framework of the discrete dipole approximation

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We consider the simulation of scattering of the high-order vector Bessel beam in the framework of the discrete dipole approximation (DDA). For this purpose, a new general classification of all existing types of Bessel beams was developed. Next, we implemented these beams in the ADDA package – an open-source parallel implementation of the DDA. This enables easy and efficient simulation of Bessel beams scattering by arbitrary-shaped particles.

INTRODUCTION

Today Bessel beams are at the frontier of different types of structured light with orbital angular momentum. One of the most important advantages of Bessel beams is their "diffractionlessness", i.e. the ability to propagate while maintaining the profile near the beam axis. These beams are actively used in such areas as optical manipulation (tweezing), material proceeding, imaging, etc. In many physical problems, it is important to take into account the scattering of Bessel beams, which is much better studied for spherical particles with the use of the generalized Lorenz-Mie theory (GLMT) [1] than for arbitrary particles. Moreover, there are a variety of existing types of Bessel beams that have been barely named [2], with neither a complete picture nor clear relations between them. In this regard, this work has two goals: the classification of various types of high-order vector Bessel beams and the development of capability to simulate scattering of any such beam by arbitrary particle using the discrete dipole approximation.

BESSEL BEAM CLASSIFICATION

Unlike a scalar Bessel beam obtained by J. Durnin [3] as a solution of scalar Helmholtz equation in a cylindrical coordinate system, its vectorial solutions – vector Bessel beams can be presented in several different forms or types. These types differ by their polarizations, field, and energy configurations. Among them are beams with circularly symmetric energy density (CS type), with transverse electric and magnetic fields – TE and TM types, respectively, and LE and LM – beams with linear polarizations of electric and magnetic fields, respectively. In order to classify them, we developed a new description of various polarizations through the 2x2 matrix **M**, associated with the Hertz vector potentials. This approach makes it possible to obtain all relations between different Bessel beam types and their polarizations. Also, within this framework, we managed to relate beams of different orders using the rotation and duality operators acting on the matrix **M**.

IMPLEMENTATION AND RESULTS

The above theoretical results were applied to generalize the scattering matrices calculus (Muller and amplitude matrix) for vortex beams i.e. beams with non-zero orbital angular momentum, which is used in many implementations of the discrete dipole approximation, including a popular open-source ADDA package [4]. Besides the standard Bessel beam types, we have implemented a generalized Bessel beam specified by a matrix **M** (4 complex values) in ADDA. The latter can be considered a linear combination of 4 basic beams (x, y – polarizations of LE and LM types). We successfully validated this implementation against the reference results of GLMT for spheres [5]. Currently, it is available at a separate fork of ADDA: https://github.com/stefaniagl/adda.

In conclusion, it is now easy for anyone to simulate the scattering of various Bessel beams by particles with arbitrary shape and internal structure. The obtained theoretical results clarify the general picture and relations between various types of Bessel beams. Similar considerations can potentially be applied to other complex light beams.

REFERENCES

[1] Lock JA, Gouesbet G. Generalized Lorenz–Mie theory and applications. J Quant Spectrosc Radiat Transf 2009;110:800–7.

[2] Wang JJ, Wriedt T, Lock JA, Jiao YC. General description of transverse mode Bessel beams and construction of basis Bessel fields. J Quant Spectrosc Radiat Transf 2017;195:8–17.

[3] Durnin J. Exact solutions for nondiffracting beams. I. The scalar theory. J Opt Soc Am A 1987;4:651.

[4] Yurkin MA. Current capabilities of the discrete dipole approximation for very large particles: speed, accuracy, and computational tricks. In: Wriedt T, Hoekstra AG, editors. Proceedings of the DDA-Workshop; 2007 Mar. 23; Bremen, Germany. p. 31–3.

[5] Chen Z, Han Y, Cui Z, Shi X. Scattering of a zero-order Bessel beam by a concentric sphere. J Opt 2014;16:055701.