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SphericalScattering: A Julia Package for Electromagnetic Scattering from Spherical Objects

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Summary

When electromagnetic fields are impinging on objects of various kinds, determining the scattered field as a solution to Maxwell's equations is crucial for many applications. For example, when monitoring the position of an airplane by a radar, the scattering behavior of the airplane plays a pivotal role and, thus, needs to be studied. Analytical approaches, however, to characterize such scattering behavior are rarely known. Some of the few exceptions where at least semi-analytical descriptions are available are metallic or dielectric spherical objects excited by time-harmonic or static fields (Jin, 2015; Ruck et al., 1970). In some applications, these canonical scattering problems are the study subject of interest. In other areas, solutions to the scattering from spherical objects rather serve as a means to verify the correctness of more involved numerical techniques, which allow to analyze the scattering from real-world objects, for instance, via finite element or integral equation methods (Adrian et al., 2021; Harrington, 1993; Jin, 2015; Rao et al., 1982). Hence, semi-analytical descriptions for the scattering from spherical objects facilitate a reproducible and comparable verification of approaches to solve electromagnetic scattering problems.

Statement of need

`SphericalScattering` is a Julia package (Bezanson et al., 2017) providing semi-analytical solutions to the scattering of time-harmonic as well as static electromagnetic fields from spherical objects (including the Mie solutions for plane wave excitations). To this end, series expansions are evaluated with special care to obtain accurate solutions down to the static limit. The series expansions are based on expressing the incident and scattered fields in terms of spherical wave functions such that the boundary conditions can be enforced at interfaces of different materials yielding the expansion coefficients of the spherical wave functions of the scattered field (Jin, 2015; Ruck et al., 1970).

Other available implementations have a different focus, that is, specific 2D scenarios are addressed (Blankrot & Heitzinger, 2018), T-matrices are employed for general shaped objects (Egel et al., 2017-09; Art Gower & Deakin, 2018; Parker, 2022; Schebarchov et al., 2021), ensemble averaged waves are obtained (Artur Gower, 2020), spontaneous decay rates of a dipole are studied (Rasskazov et al., 2020), light scattering is considered employing only plane waves as excitations (chillin-capybara, 2022; Ladutenko et al., 2017; Leinonen, 2016; Prahl, 2023; Schäfer, 2023; Walter, 2023; Wu, 2023), or only far-field quantities are computed.

In contrast, in `SphericalScattering` a variety of excitations is available, that is,

- plane waves,
- fields of electric/magnetic ring currents,
- fields of electric/magnetic dipoles,

- transverse electric (TE) and transverse magnetic (TM) spherical vector waves, and
- uniform static electric fields,

where several parameters including the orientation, direction, or polarization of the sources can be set by the user and are not predefined. The scattered far- and near-fields are then obtained following (Hansen, 1988; Jackson, 1999; Jin, 2015; Jones, 1995; Ruck et al., 1970; Sihvola & Lindell, 1988) for

- perfectly electrically conducting (PEC) spheres and
- dielectric spheres

all via a unified interface. In consequence, `SphericalScattering` is a useful (code-) verification tool in the area of electromagnetic scattering for a wide range of scenarios. For this purpose, it has already been employed in scientific publications (Hofmann et al., 2022a, 2023a, 2021, 2022b, 2023b, 2023c, 2023d).

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References

Adrian, S. B., Dély, A., Consoli, D., Merlini, A., & Andriulli, F. P. (2021). Electromagnetic integral equations: Insights in conditioning and preconditioning. *IEEE Open Journal of Antennas and Propagation*, 1143–1174. https://doi.org/10.1109/OJAP.2021.3121097

Bezanson, J., Edelman, A., Karpinski, S., & Shah, V. B. (2017). Julia: A fresh approach to numerical computing. *SIAM Review*, *59*(1), 65–98. https://doi.org/10.1137/141000671

Blankrot, B., & Heitzinger, C. (2018). ParticleScattering: Solving and optimizing multiple-scattering problems in Julia. *Journal of Open Source Software*, *3*(25), 691. https://doi.org/10.21105/joss.00691

chillin-capybara. (2022). Cppmie. In *GitHub repository*. GitHub. https://github.com/chillin-capybara/cppmie

Egel, A., Pattelli, L., Mazzamuto, G., Wiersma, D. S., & Lemmer, U. (2017-09). CELES: CUDA-accelerated simulation of electromagnetic scattering by large ensembles of spheres. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *199*, 103–110. https://doi.org/10.1016/j.jqsrt.2017.05.010

Gower, Artur. (2020). EffectiveWaves. In *GitHub repository*. GitHub. https://github.com/JuliaWaveScattering/EffectiveWaves.jl

Gower, Art, & Deakin, J. (2018). *MultipleScattering.jl* (Version v0.1.1). Zenodo. https://doi.org/10.5281/zenodo.1213225

Hansen, J. E. (1988). *Spherical near-field antenna measurements*. The Institution of Engineering; Technology. ISBN: 978-0-86341-110-6

Harrington, R. F. (1993). *Field computation by moment methods* (Reprint Edition). Wiley-IEEE Press. ISBN: 978-0-7803-1014-8

Hofmann, B., Eibert, T. F., Andriulli, F. P., & Adrian, S. B. (2022a). Low-frequency-stabilized electric field integral equation on topologically non-trivial geometries for arbitrary excitations. *Proc. IEEE Antennas Propag. Soc. Int. Symp. URSI Nat. Radio Sci. Meeting*, 1938–1939. https://doi.org/10.1109/AP-S/USNC-URSI47032.2022.9886833

Hofmann, B., Eibert, T. F., Andriulli, F. P., & Adrian, S. B. (2023a). Towards a self-adaptive frequency normalization scheme for the low-frequency stabilized magnetic field integral equation. *Proc. IEEE Antennas Propag. Soc. Int. Symp. URSI Nat. Radio Sci. Meeting*, 1213–1214. https://doi.org/10.1109/USNC-URSI52151.2023.10238214

Hofmann, B., Eibert, T. F., Andriulli, F. P., & Adrian, S. B. (2021, December). Low-frequency stable discretization of the electric field integral equation based on Poincaré's lemma. *Proc. IEEE Antennas Propag. Soc. Int. Symp. URSI Nat. Radio Sci. Meeting*. https://doi.org/10.1109/APS/URSI47566.2021.9703799

Hofmann, B., Eibert, T. F., Andriulli, F. P., & Adrian, S. B. (2022b, March). Efficient combination of scalar-potential representations of solenoidal functions and quasi-Helmholtz projectors. *16th European Conference on Antennas and Propagation (EuCAP)*. https://doi.org/10.23919/EuCAP53622.2022.9769650

Hofmann, B., Eibert, T. F., Andriulli, F. P., & Adrian, S. B. (2023b). A low-frequency stable, excitation agnostic discretization of the right-hand side for the electric field integral equation on multiply-connected geometries. *IEEE Transactions on Antennas and Propagation*. https://doi.org/10.1109/TAP.2023.3234704

Hofmann, B., Eibert, T. F., Andriulli, F. P., & Adrian, S. B. (2023c, March). Investigations on the low-frequency stability of inverse surface source field transformations based on the electric field integral operator. *17th European Conference on Antennas and Propagation (EuCAP)*. https://doi.org/10.23919/EuCAP57121.2023.10133154

Hofmann, B., Eibert, T. F., Andriulli, F. P., & Adrian, S. B. (2023d). An excitation-aware and self-adaptive frequency normalization for low-frequency stabilized electric field integral equation formulations. *IEEE Transactions on Antennas and Propagation*, *71*(5), 4301–4314. https://doi.org/10.1109/TAP.2023.3247896

Jackson, J. D. (1999). *Classical electrodynamics*. Wiley. ISBN: 0-471-30932-X

Jin, J.-M. (2015). *Theory and computation of electromagnetic fields* (Second edition). John Wiley & Sons, Inc. ISBN: 978-1-119-10804-7

Jones, T. B. (1995). Models for layered spherical particles. *Electromechanics of Particles*, 227–235. https://doi.org/10.1017/CBO9780511574498

Ladutenko, K., Rodríguez, O. P., Müller, P., & Badger, T. G. (2017). *Scattnlay* (Version v2.0.1). Zenodo. https://doi.org/10.5281/zenodo.248729

Leinonen, J. (2016). Pymiecoated. In *GitHub repository*. GitHub. https://github.com/jleinonen/pymiecoated/tree/master

Parker, J. (2022). MiePy. In *GitHub repository*. GitHub. https://github.com/johnaparker/miepy

Prahl, S. (2023). *miepython: Pure Python implementation of Mie scattering*. Zenodo. https://doi.org/10.5281/zenodo.7949263

Rao, S., Wilton, D., & Glisson, A. (1982). Electromagnetic scattering by surfaces of arbitrary shape. *IEEE Transactions on Antennas and Propagation*, *30*(3), 409–418. https://doi.org/10.1109/TAP.1982.1142818

Rasskazov, I. L., Carney, P. S., & Moroz, A. (2020). STRATIFY: A comprehensive and versatile MATLAB code for a multilayered sphere. *OSA Continuum*, *3*(8), 2290–2306. https://doi.org/10.1364/OSAC.399979

Ruck, G. T., Barrick, D. E., Stuart, W. D., & Krichbaum, C. K. (1970). *Radar cross section handbook* (Vol. 1). Plenum Press. ISBN: 978-1-4899-5326-1

Schäfer, J. (2023). MatScat. In *MATLAB Central File Exchange*. MATLAB. https://www.mathworks.com/matlabcentral/fileexchange/36831-matscat

Schebarchov, D., Fazel-Najafabadi, A., Le Ru, E., & Auguié, B. (2021). *TERMS* (Version 1.0.0). Zenodo. https://doi.org/10.5281/zenodo.5703291

Sihvola, A., & Lindell, I. V. (1988). Transmission line analogy for calculating the effective permittivity of mixtures with spherical multilayer scatterers. *Journal of Electromagnetic Waves and Applications*, *2*(8), 741–756. https://www.tandfonline.com/doi/abs/10.1163/156939388X00044

Walter, N. (2023). Mie electric field simulation for spheres. In *MATLAB Central File Exchange*. MATLAB. https://www.mathworks.com/matlabcentral/fileexchange/66845-mie-electric-field-simulation-for-spheres

Wu, G. (2023). MieScattering. In *GitHub repository*. GitHub. https://github.com/JuliaRemoteSensing/MieScattering.jl