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RETRIEVING THE SIZE OF PARTICLES WITH ROUGH SURFACES FROM 2D SCATTERING PATTERNS

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ABSTRACT. Frequency analysis can be used for the recovery of particle properties such as size from scattering data, but is difficult to apply in practice, as lack of completeness or discontinuities at boundaries can produce artifacts. For 2D scattering patterns image processing, including morphological operations, offers an alternative approach. We test possible techniques on a diverse range of particles. It is found that the average surface area of intensity peaks is inversely proportional to particle size.

1. Introduction

Small particle properties like size are most often retrieved from the dependence of scattering on the polar (scattering) angle. This angular dependence of scattering is a function of the size parameter of the particle. For single or monodisperse particles this dependence is typically characterized by the presence of oscillations which phenomenologically can be thought of as interference patterns, and mathematically are a manifestation of the presence of periodic functions (e.g. Legendre functions for spheres) in the expansions of the scattered field. The larger the size parameter, the higher the frequency of these oscillations - a reflection of the presence of functions of increasing order in the expansions. Intuitively, therefore, frequency analysis of scattering patterns can be expected to yield particle size information. For example, the cutoff order in Gegenbauer polynomial expansions of phase functions is proportional to the size parameter of spheres, although in practice such analysis may require the knowledge of near-complete angular range of the phase function [1].

The azimuthal dependence of scattering from nonspherical particles can be used to recover information about their size, shape and orientation, although strong a priori assumptions must be made. It has also been shown that some particle information is retained even in the azimuthal frequency spectrum, as demonstrated by the recovery of the size and aspect ratio of prismatic ice crystals [2, 3]. Additional properties can be expected to be obtained from two-dimensional (2D) scattering patterns (also called two-dimensional angular

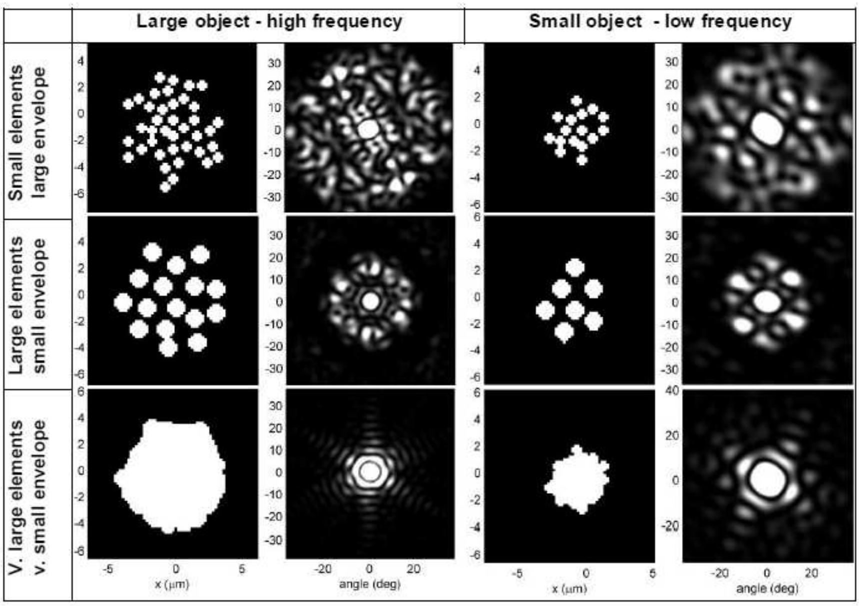

Figure 1. Composite apertures (columns 1 and 3) and corresponding diffraction patterns (columns 2 and 4), computed using FFT for 532 nm wavelength.

optical scattering, TAOS) by virtue of greater information content of the data, although the inversion process is non-trivial [4, 5]. One such property is particle roughness, which is associated with the presence of speckle in the 2D patterns, and can be recovered through texture analysis, as more roughness equates with more speckle [6, 7]. The existence of the speckle offers the prospect of size recovery too: for example, it was established in experiments with sphere clusters that the number of intensity peaks (”islands”) in the 2D patterns was proportional to the overall size of the clusters [8]. This property is not surprising, and can be easily illustrated by examining a simplified case: Fraunhofer diffraction patterns from composite apertures, consisting of varying numbers of pseudo-randomly distributed elements (pinholes). In such a system far-field diffraction can be described using 2D fast Fourier transforms (FFT) of binary arrays - see Fig. 1. Examination of the patterns, which can be thought of as 2D angular spectra, reveals two trends. Firstly, larger overall apertures produce smaller spots (intensity peaks) - fast *modulation* frequency. Secondly, larger elements produce smaller pattern *envelopes* (narrower spectra), but with similarly sized spots. These characteristics of the 2D patterns suggest that frequency or texture analysis of patterns in the forward scattering region (which is dominated by diffraction) may offer ways of retrieving particle size. While the size can be obtained from integrated scattered intensity, this process depends on calibration and is subject to various errors, so an alternative procedure that does not depend on intensity measurement may in some cases be preferable. This is the main subject of our investigation.

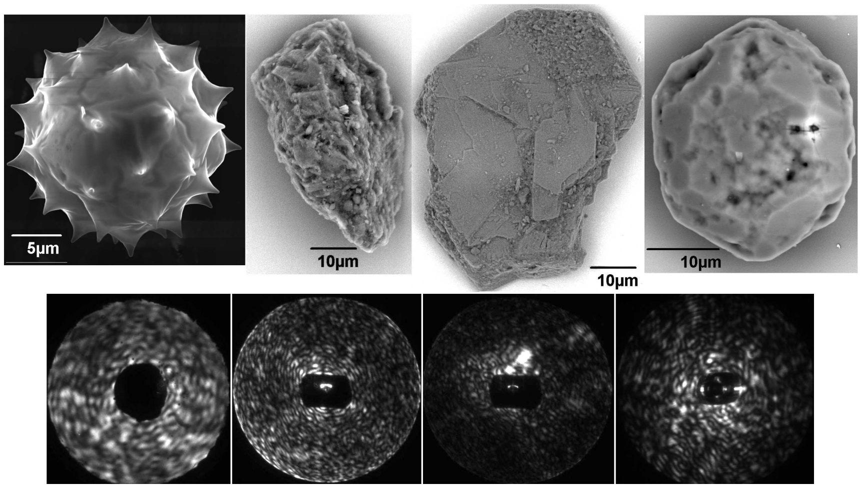

Figure 2. SEM images (top) and scattering patterns (bottom) of, from left: *Matricaria recutita* pollen, rough and smooth mineral dust grains and rough ice analogue plate.

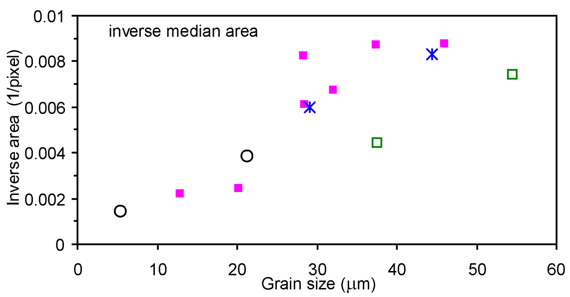

Figure 3. Inverse of median area of intensity peaks in 2D SID-3 patterns from living cells (open circles), rough mineral dust grains (filled squares), smooth mineral dust grains (open squares) and ice analogue crystals (asterisks).

2. Methods

The Small Ice Detector model 3 (SID-3) aircraft probe and its laboratory implementations use intensified CCD cameras to capture 2D patterns for a range of scattering angles up to 25°, with the central, low-angle region obscured by a beam stop. Single particles are illuminated by a laser beam with a wavelength of 532 nm [9]. SID-3 2D patterns were obtained from single particles deposited on anti-reflection coated glass windows, including rough and smooth mineral dust grains, ice analogue crystals (refractive index 1.31) [10], and living cells (fungal spores and pollen grains). Numbers and surface areas of intensity peaks in the 2D patterns were calculated using image processing and morphology techniques similar to those used by Fernandes *et al*. [11]. Particle size was obtained from microscopy images as the diameter of same area circle.

3. Results

Scanning electron microscopy (SEM) images of example particles and their corresponding SID-3 2D scattering patterns are shown in Fig. 2.

Figure 3 shows that the median surface area of intensity peaks was approximately inversely proportional to the size of the particles, irrespectively of their origin or refractive index. The number of peaks was directly proportional to the size. However, the clearest relationships existed for particles with rough surfaces.

Acknowledgments

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