Inverse Obstacle Scattering and Linear Classification

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Abstract—

Experimental: TAOS (two-dimensional angle-resolved optical scattering) is an experimental method to detect single, micrometer-sized airborne material particles, illuminate them by a single pulse of laser ($\lambda = 532\,\text{nm}$, pulse duration $= 30\,\text{ns}$) and record their scattered light intensity patterns over the angular sector $\{75° \le \theta \le 135°\} \times \{0° \le \varphi \le 360°\}$ at high resolution (one pattern $\doteq 1024^2$ pixels). Particles of reference materials and from outdoor environmental sampling have been analyzed and thousands of scattering patterns (TAOS patterns, hereinafter) have been stored [1]. Examples of reference materials are: $2.8\,\mu\text{m}$ dioctyl phthalate droplets (label: Fq), $1.03\,\mu\text{m}$ dried polystyrene latex spheres (Pq), *Bacillus subtilis* spores (Bq). Examples of environmental materials are: unsorted diesel engine soot (sq) and airborne dust from rooftop sampling (labeled $K0$ to $K5$).

Problem: The Inversion of Scattering Patterns: The problem of determining the size, shape, and complex refractive index of the particle (the scatterer) from its TAOS pattern corresponds to reconstructing an obstacle from a single incident wavevector and the intensity of the scattered wave. No theoretical result is available to date.

Solution: Feature Extraction for Linear Classification: For the past eight years the first author has worked at recasting the inverse problem into statistical terms and replacing obstacle reconstruction by the assignment of a TAOS pattern to a class. An algorithm has been developed, whereby two modules interact: feature extraction [2] and linear classification. In the current implementation (2012 to present) the former module regards the TAOS pattern as an image, applies a windowed Fourier transform followed by non-linear operations and yields a feature vector. The linear classifier applies multivariate statistics to feature vectors. Training and validation are supervised and rely on sequences of training sets made e.g., from Fq, Pq and Bq patterns. Once validated, the classifier is applied to recognize other patterns. The assignment of a TAOS pattern to a class relies on a fusion rule.

Classification Results: One of the goals of classification is the discrimination of bacterial spore patterns (Bq). Figure 2 provides a typical result: a set of 969 $K5$ (outdoor dust) patterns is analysed; 98 patterns (10%) are falsely recognised as Bq (lower halfplane), whereas the remainder is assigned to the other two training classes, Fq (top) and Pq (middle). Further details are provided by the caption.

Each of the 957 $K5$ TAOS patterns is represented by a point on the plane $\{z_1, z_2\}$ of the first two principal components, has a label, and is assigned to a class: Bq (blue), or Pq (green) or Fq (cyan). Counterclockwise, from top left, {pattern, assigned class, label} and, between parentheses, the pattern distinctive feature, which may justify assignment: $\{K5034, Fq, 124\}$ (curls), $\{K5024, Pq, 115\}$ (curls), $\{K5016, Bq, 107\}$ (coarse feature), $\{K5008, Bq, 184\}$ (coarse patch), $\{K5069, Pq, 159\}$ (wide rings), and $\{K5094, Fq, 99\}$ (rings).

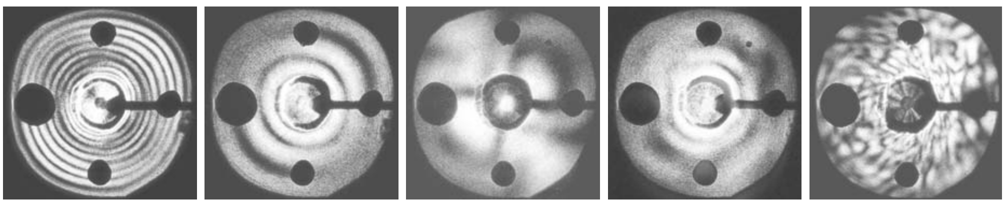

Figure 1: TAOS patterns, left to right, from a dioctyl phthalate droplet (Fq, narrow rings), a dried polystyrene latex sphere (Pq, wide rings), a single *Bacillus subtilis* spore (Bq, bowtie), an aggregate of diesel engine soot particles (sq, no special structure), and outdoor sampling ($K5$, almost random patches). The polarisation of the incident wave is $+45\,\text{deg}$. Contrast has been enhanced by the Equalize command of GIMP for display purposes only.

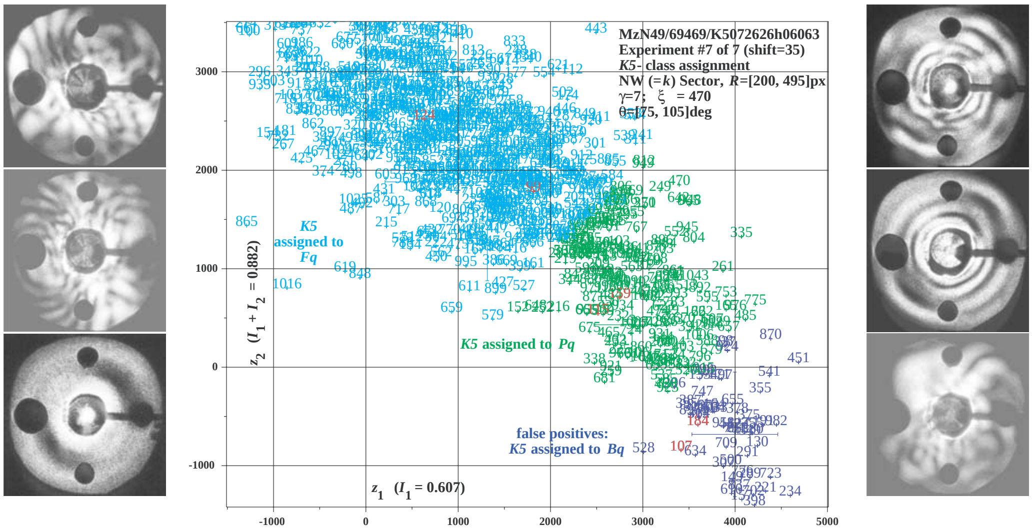

Figure 2: Recognition of 957 TAOS patterns from outdoor sampling ($K5$ set).

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