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 ($\lambda = 532$ nm, pulse duration = 30 ns) and record their scattered light intensity patterns over the angular sector $\{75^\circ \leq \theta \leq 135^\circ\} \times \{0^\circ \leq \varphi \leq 360^\circ\}$ at high resolution (one pattern $= 1024^2$ 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 $\mu$m dioctyl phthalate droplets (label: $F_q$), 1.03 $\mu$m dried polystyrene latex spheres ($P_q$), Bacillus subtilis spores ($B_q$). Examples of environmental materials are: unsorted diesel engine soot ($sq$) and airborne dust from rooftop sampling (labeled $K_0$ to $K_5$).

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 $F_q$, $P_q$ and $B_q$ 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 ($B_q$). Figure 2 provides a typical result: a set of 969 $K_5$ (outdoor dust) patterns is analyzed: 98 patterns (10%) are falsely recognized as $B_q$ (lower halfplane), whereas the remainder is assigned to the other two training classes, $F_q$ (top) and $P_q$ (middle). Further details are provided by the caption.

Each of the 957 $K_5$ 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: $B_q$ (blue), or $P_q$ (green) or $F_q$ (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 ($F_q$, narrow rings), a dried polystyrene latex sphere ($P_q$, wide rings), a single Bacillus subtilis spore ($B_q$, bowtie), an aggregate of diesel engine soot particles ($sq$, no special structure), and outdoor sampling ($K_5$, almost random patches). The polarisation of the incident wave is +45 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).

ACKNOWLEDGMENT
G. F. C. gratefully acknowledges the financial support of Contract W911NF 11-1-0277 R&D 1449-BC-01 granted to Università Milan-Bicocca by the US Army RDECOM ACQ CTR.

REFERENCES