

Reflective polarization holography and deep learning for opaque microplastics and surface biofilms identification

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Abstract: We present a reflective polarization holographic system integrated with deep learning to accurately identify opaque microplastics and characterize their surface microbial biofilms in complex environments.

1. Introduction

Microplastic (MP) pollution has become a global environmental crisis, with particles acting as vectors for various contaminants and microbial communities, known as the “plastisphere” [1, 2]. While transmission-mode digital holography has shown promise for transparent MPs, it remains ineffective for opaque particles (e.g., tire wear, dark polymers). Furthermore, characterizing the thin, irregular biofilms on MP surfaces requires high-sensitivity phase and polarization analysis [3–5]. This study introduces a deep learning-enhanced reflective polarization digital holography (RPDH) system to address these challenges.

2. Method

The reflective polarization digital holographic system has a compact system structure. The system uses a 532 nm laser source, as shown in Fig. 1. A polarization-sensitive camera captures the interference between the reference beam and the light reflected from the MP surface. By employing a Stokes polarization mask, we simultaneously retrieve four linear polarization states ($I_0^\circ, I_{45}^\circ, I_{90}^\circ, I_{135}^\circ$), enabling the calculation of the full Stokes vector (S_0, S_1, S_2), the degree of linear polarization, and angle of polarization.

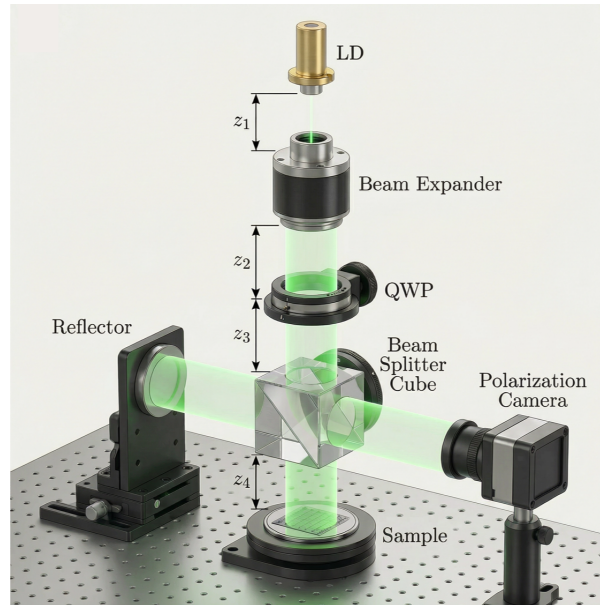


Fig. 1. The schematic diagram for the reflective polarization holographic system. LD: laser diode; QWP: quarter-wavelength plate.

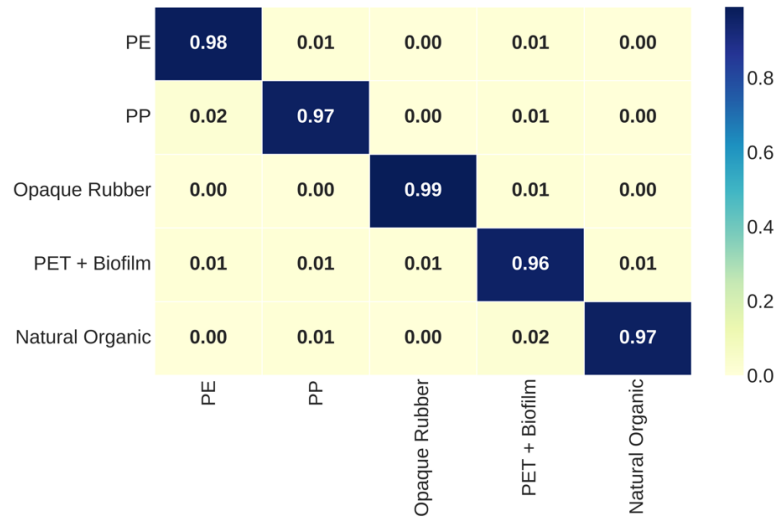


Fig. 2. Confusion matrix for the identification results of opaque microplastics and other environmental particles.

A dual-branch convolutional neural network is developed to process the reconstructed amplitude and phase maps alongside the polarization signatures. The “morphology branch” extracts surface roughness and fractal dimensions, while the “polarization branch” identifies material-specific Mueller matrix components. For biofilm detection, a Physics-Informed Neural Network (PINN) [6] is utilized to model the light scattering from the biofilm-plastic interface, allowing for the estimation of biofilm thickness and biomass density.

3. Experiments and Results

Experimental results demonstrate that RPDH effectively overcomes the opacity barrier, providing high-contrast 3D profiles of black rubber and weathered PE particles. The integration of polarization data significantly enhances the discrimination between synthetic polymers and natural organic matter (e.g., wood chips). The AI model successfully identified microbial colonization patterns, showing that biofilms increase surface depolarization and modify the local complex refractive index. This multi-modal approach allows for the first time the simultaneous assessment of MP type and its ecological state (e.g., weathering).

4. Conclusion

The proposed deep learning-enhanced RPDH system provides a robust tool for environmental monitoring, offering unprecedented insights into the physical and biological characteristics of opaque microplastics. Future work will focus on extending the system application regions to environmental pollution monitoring.

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