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Polarization-sensitive digital holography for microplastic identification through scattering media

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Abstract: A polarization-sensitive holographic imaging system is designed for identifying transparent microplastics (MPs) through scattering media. The degree of linear polarization (DoLP) is an angle-independent feature for distinguishing different types of MPs.

1. Introduction

Microplastic (MP) is one of the most concerning pollutants, which has been extensively dispersed in water, soil, and air, posing a risk to human health and the environment [1]. Conventional MP detection methods (e.g., μ-FTIR and μ-Raman spectroscopy) are costly, labor-intensive, and time-consuming. Thus, a portable detection system with high throughput is urgently desired for global MP assessment. Digital holography (DH) is a versatile imaging technique that has great potential for rapid MP detection and characterization [2, 3]. However, identifying MPs in natural environments is still challenging because of the large variations in their physical and chemical properties. More effort should be devoted to feature extraction and quantification. Besides, when identifying MPs in aquatic scenarios, the influence of scattering media has not been investigated yet.

In this work, a polarization-sensitive holographic imaging system is designed, which is capable of providing both polarimetric and holographic information of the target in a snapshot. Furthermore, the influence of scattering media on the imaging system is experimentally studied.

2. Polarization-sensitive digital holography

As shown in Fig. 1(a), the illumination light is a circularly polarized laser beam ($\lambda = 532\,\text{nm}$). MP particles are randomly placed on a glass slide. The resulting holographic fringes are recorded by a polarized imaging sensor (MC-A500P-163) that can simultaneously resolve the intensity of linear polarization in four directions (0°, 45°, 90°, and 135°) [4]. Numerical back propagation is employed to reconstruct the amplitude distribution. Then, with an autofocusing algorithm [5], the shape, size, and 3D location of the particles can be determined. Linear Stokes parameters are adopted to describe the polarization of the light:

$$I(x,y) = I^{0}(x,y) + I^{90}(x,y), \tag{1}$$

$$Q(x,y) = I^{0}(x,y) - I^{90}(x,y), \tag{2}$$

$$U(x,y) = I^{45}(x,y) - I^{135}(x,y). \tag{3}$$

Furthermore, to characterize the polarization response of MPs, specific polarization parameters can be deduced from Stokes parameters, such as the degree of linear polarization (DoLP $\in [0,1]$):

$$\text{DoLP}(x,y) = \frac{\sqrt{Q^2(x,y) + U^2(x,y)}}{I(x,y)}, \tag{4}$$

and the angle of polarization (AoP $\in [-\frac{\pi}{4}, +\frac{\pi}{4}]$):

$$\text{AoP}(x,y) = \frac{1}{2}\tan^{-1}\frac{U(x,y)}{Q(x,y)}. \tag{5}$$

More polarization parameters could be derived from the captured holographic images, such as Mueller matrix [6]. A comprehensive analysis of these parameters is required to determine whether they are reliable for MP classification.

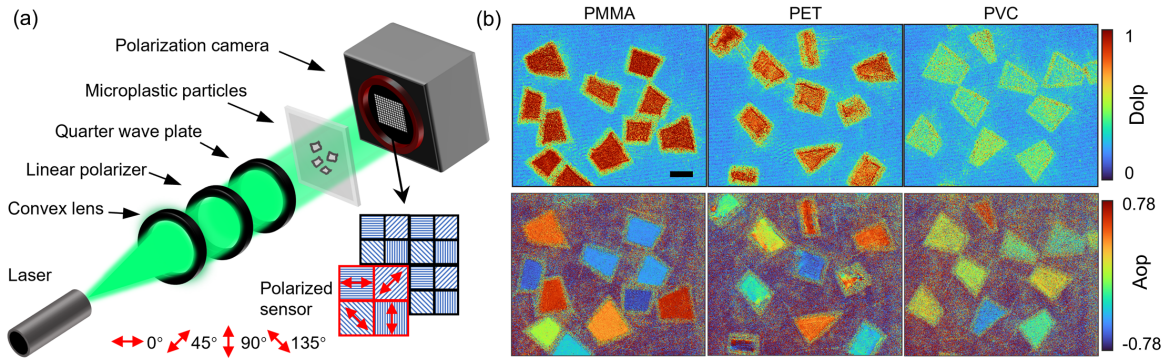

Fig. 1. (a) Experimental setup. (b) DoLP and AoP of three testing samples. Scalebar: 1 mm.

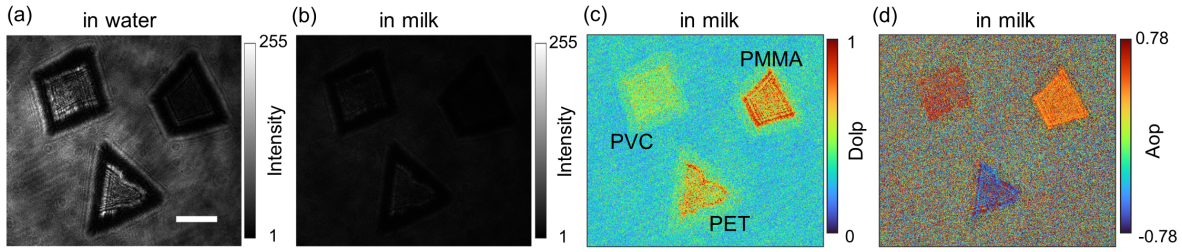

Fig. 2. Intensity of holograms recorded in pure water (a) and milk solution (b), respectively. The measured distributions of DoLP (c) and AoP (d) in milk solution. Scalebar: 1 mm.

3. Results and discussion

Three types of transparent MPs, i.e., polymethyl methacrylate (PMMA), polyethylene terephthalate (PET), and polyvinyl chloride (PVC), were tested in this work. As illustrated in Fig. 1(b), DoLP is a distinguishable characteristic of the MPs, inspecting the optical anisotropy of materials. Additionally, the DoLP distributions of the same MP type are consistent, which indicates that DoLP is independent of the optical axis angle of the MPs. Although AoP is an angle-dependent parameter, it can improve image contrast for particle segmentation.

To evaluate the performance of the imaging system in aquatic environments, MP particles were suspended in pure water and milk solution (scattering media) for detection, respectively. As shown in Fig. 2, under the same exposure time of 50 ms, the image intensity and contrast dramatically decreased when passing through the scattering media. A certain degree of depolarization due to the scattering effect can be observed from the DoLP and AoP measurements. However, the designed system can still accurately determine the shape, size, position, and category of the MP particles. Lastly, by extracting more optical features from the images, the robustness of this system could be further improved for in-situ monitoring of MP pollution.

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