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Characterization of Laundry Microplastics Through Automated Image Analysis

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High-accuracy characterization of systems containing particles is an important challenge across many scientific disciplines. For spherical particles, ensemble-based characterization methods such as dynamic light scattering and laser diffraction can determine size. However, these methods are not accurate for real-world irregular particles [1, 2]. Direct imaging methods can provide insight into particles spanning many length scales. These tools are only sufficiently high-throughput when combined with automated image analysis.

Aqueous microplastics pose a significant threat to ecosystem and human health [3]. Despite this, no standard operating protocols for the quantification of aqueous microplastics exist [4]. Here we investigate automated image analysis of high-resolution digital photographs as an accessible characterization method for micron to millimeter sized fibrous microplastic particles. Application of this technique provides several important insights into microplastic remediation.

Fibrous microplastics produced by laundry washing constitute up to 35% of microplastics released to the environment [5]. We chose aqueous solutions of these particles as the ideal system for testing characterization with our automated imaging analysis setup. The size distribution of the microplastics (width: 12 μm, length 30-2000 μm) falls within the resolution of the digital camera and lens used (~6 μm) at a focal distance of 30 cm. The large field of view (8 x 8 cm) at this focal distance provides ample area to image a distribution of many particles without the issue of significant particle overlap. Further, we can leverage the ability of direct imaging to determine particle shape despite their highly nonuniform aspect ratio.

The fibrous microplastic particles were dispersed in water, vacuum filtered onto filter paper, and allowed to dry in a dust-free environment. A Canon EOS 5D Mark IV was used to take high resolution digital photographs of the microplastic-laden filter papers. We then processed the raw photographic images (Figure 1a) with our automated image analysis protocol. As displayed by the line profile of pixel intensity in Figure 1b, small variations in lighting conditions and inconsistency in the filter paper texture produced a non-uniform background intensity across the image. As seen in Figure 1c, this background intensity was subtracted out through a Gaussian blurring protocol. We applied the ISODATA image thresholding procedure to create a binary image as shown in Figure 1d [6]. Particle counting (identified microplastics shown in Figure 1e) was conducted using the Laplacian of the Gaussian method [7].

Microplastic samples are commonly characterized by manual counting [8]. This technique was used to verify the accuracy of the counts from our automated image analysis protocol. As seen in Figure 1f, hand counting introduced significant systemic error due to the subjective nature of this method. The algorithmically obtained counts from automated image analysis were in line with the hand counts while eliminating the bias and variability between counts by different researchers.

The practical applications of our technique were demonstrated by considering our novel floatation-based microplastic remediation protocol. The electrolysis of water at the surface of graphite electrodes was used to generate small bubbles. Hydrophobic interactions between the surface of the bubbles and the microplastics caused the bubbles to adhere to the plastics and remove them from solution via flotation. Flotation-based removal of microplastics was observed over a range of different starting microplastic concentrations (Figure 2b). The speed of remediation can be increased by tailoring the overpotential applied to the electrochemical cell. At an electrode spacing of 2cm, a current of 50 mA was optimal for remediation, with higher currents resulting in diminished remediation over time through increased system turbulence (Figure 2c). At higher voltages and currents, the formation of more bubbles results in faster remediation. At the highest applied voltages, the observed remediation decreases. We also observed that longer microplastics are typically remediated more readily than shorter microplastics in this protocol (Figure 2d). Using microplastic remediation as an example, this research demonstrates how automated image analysis provides valuable insight into the characterization of systems containing irregularly-shaped particles [9].

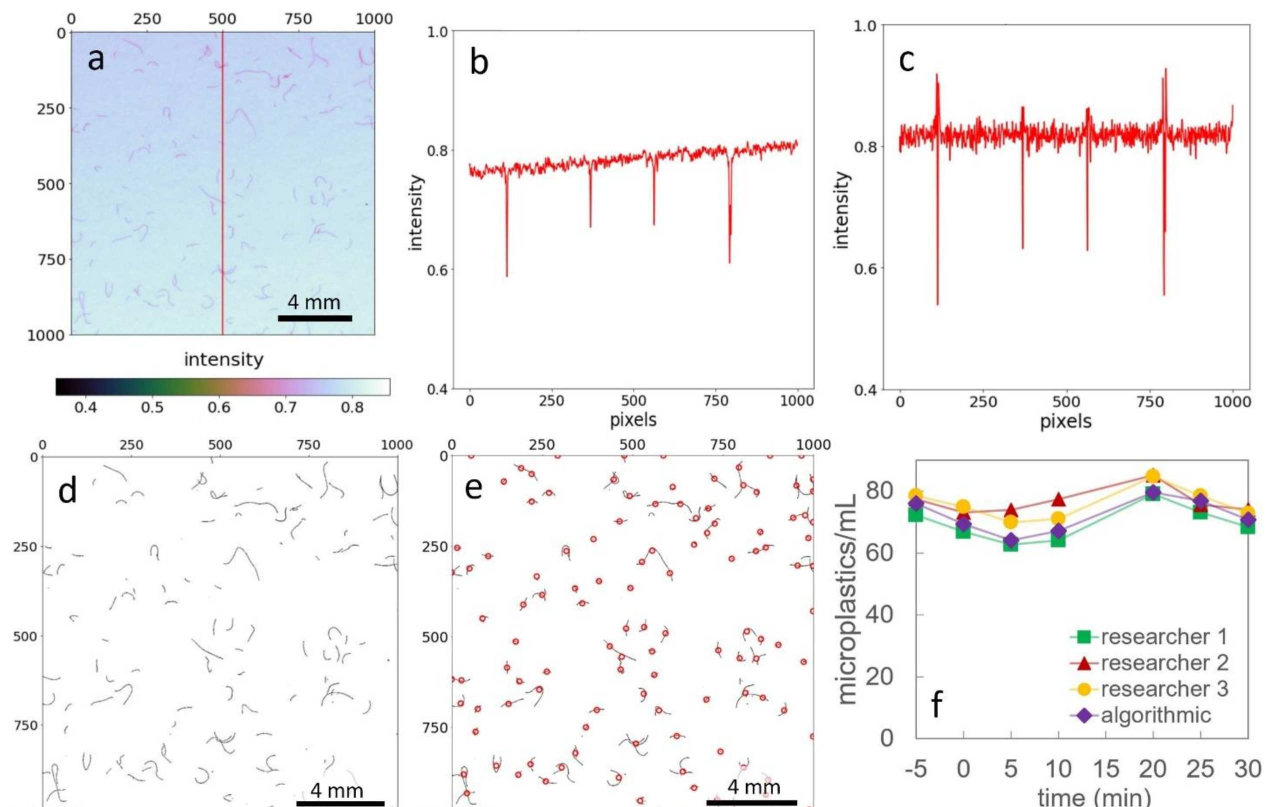

Figure 1. (a) Cropped image of typical microplastic distribution on filter paper before any image processing with (b) a line profile showing pixel intensity. (c) After background subtraction, the image has a uniform average intensity. (d) A binary image is created by applying a ISODATA thresholding procedure. (e) A Laplacian of Gaussian blob detection algorithm is used to count the particles, which are identified in red circles. (f) Algorithmic counts of microplastic-containing photographs agree with manual counts.

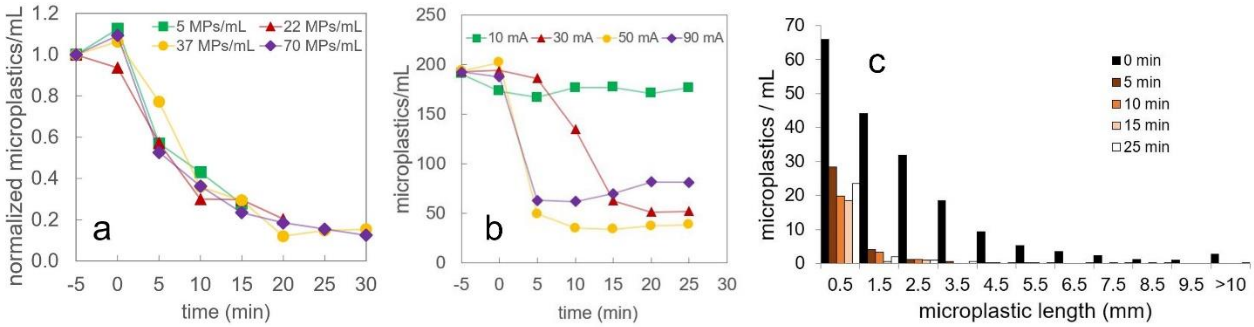

Figure 2. (a) Normalized microplastic concentration curves plotted against the time since the electrochemical system was activated at 15V. (b) Microplastic concentration curves for the same starting concentration plotted against the time since the electrochemical system was activated at different currents. (c) Microplastic length distribution at 5 time points during remediation at 15V.

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