Classification of evaporation-driven concentration changes of microdroplets of suspensions using convolutional neural network

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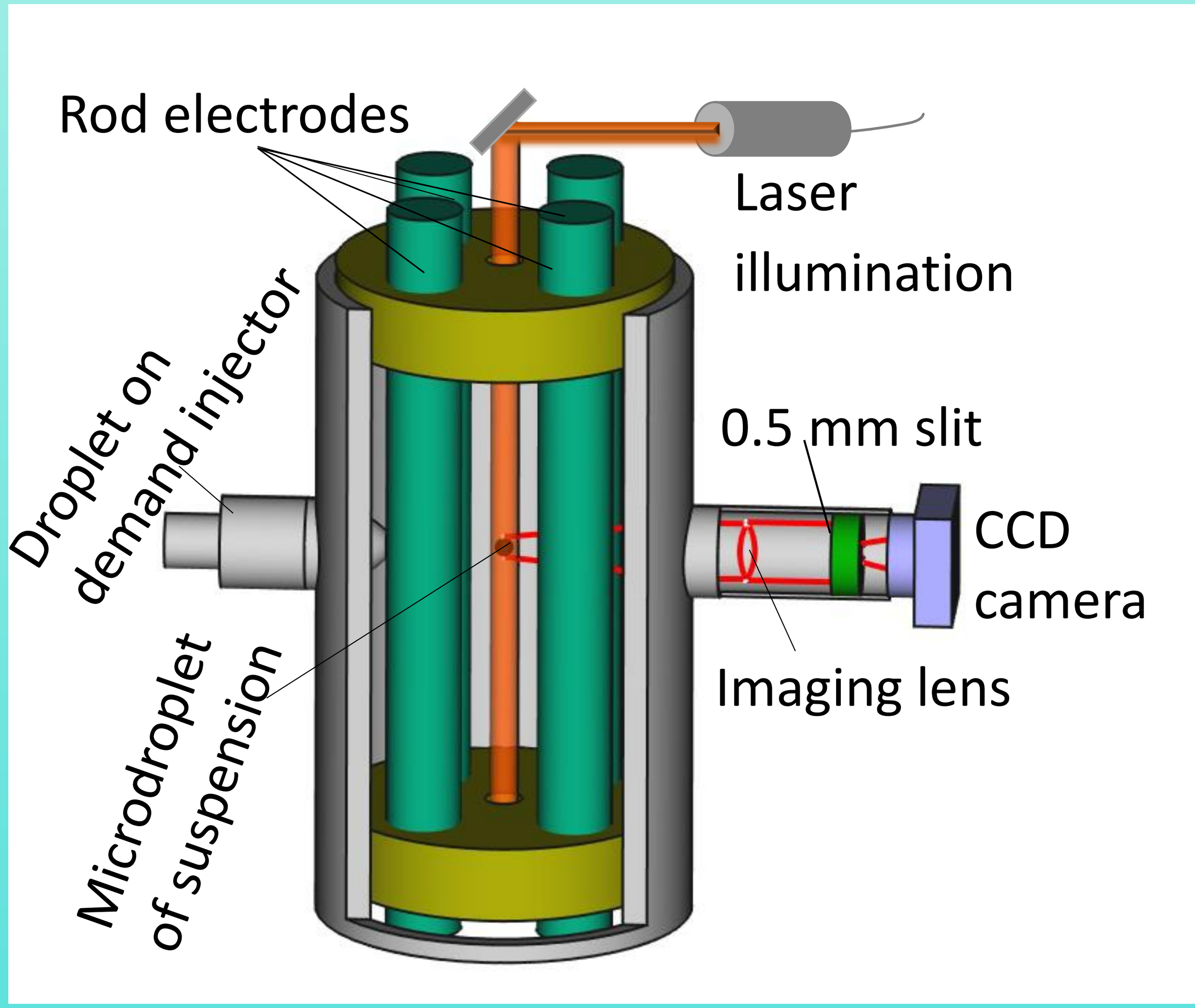
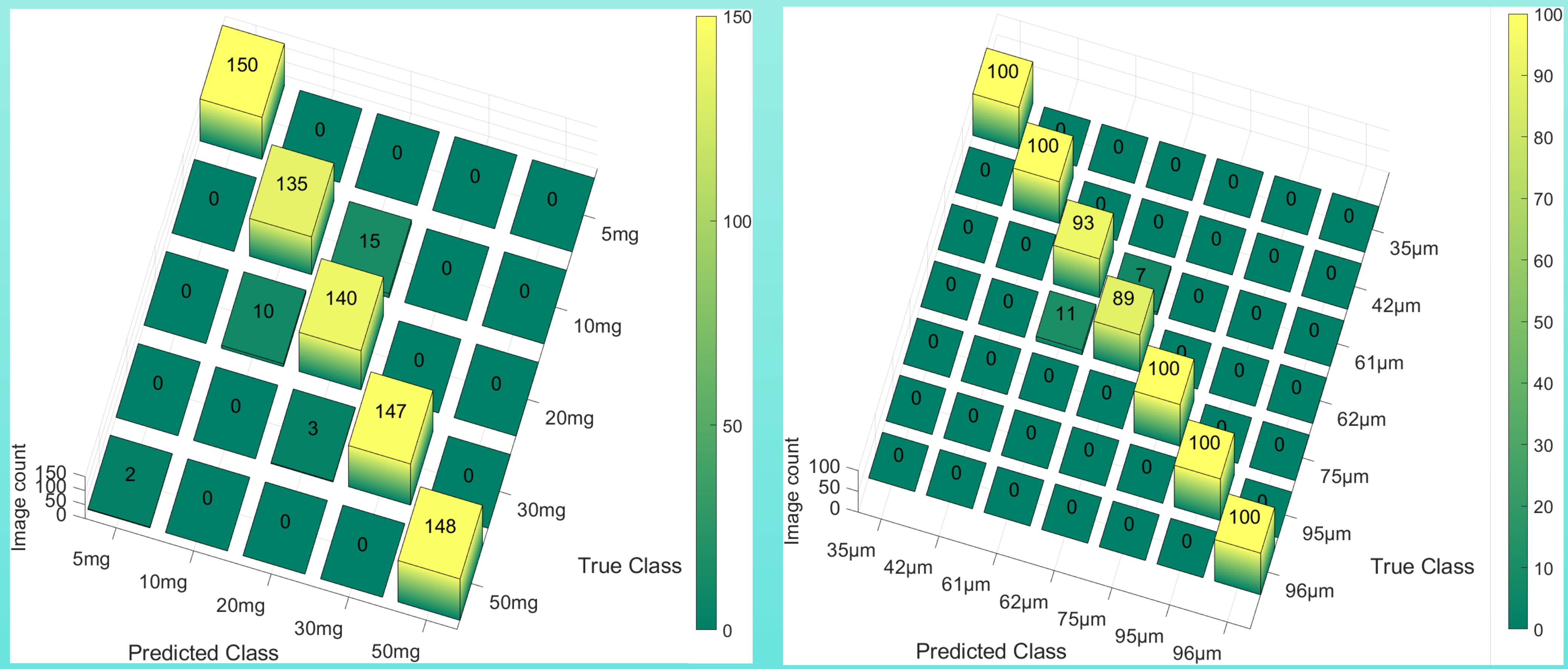
Introduction:

In the volume of an evaporating microdroplet-containing-nanoparticles, three different motions have been identified; (i) the random or Brownian motions of the individual particles [1], (ii) migrations of the particles from the interior to the surface [2] and (iii) overall movements of the particles closer to each other due to reduction in the liquid content by evaporation [1]. The Brownian motions of these individual particles result in rapid intensity variations when the droplet is illuminated. The migration to the surface by the particles (usually carrying the same charge) is driven by electrostatic repulsions. The particles then turn to stay at the surface because of self-assembling, thus making the droplet surface optically rough. The random intensity is then observed to be modulated. Finally, as a result of the continuous evaporation of the liquid, the overall composite droplet shrinks towards the center into a more compact structure and eventually a dried up aggregate [1, 2]. In this preliminary measurement, we levitated single microdroplets of colloidal suspensions in a linear electrodynamic trap and used a lens to both magnify and project the scattered light from the illuminated nanoparticles onto a CCD, forming speckle patterns. The speckle patterns were recorded at a relatively long distance to obtain optimum speckle size and contrast due to the fact that the aperture diameter must be very small to cut off the glory points from the illuminated spherical droplet.

Setup





Classification of speckle patterns recorded from microdroplets of suspensions. Left panel, different concentrations (5, 10, 20 30 and 50 mg) and right panel, different droplet sizes.

Method

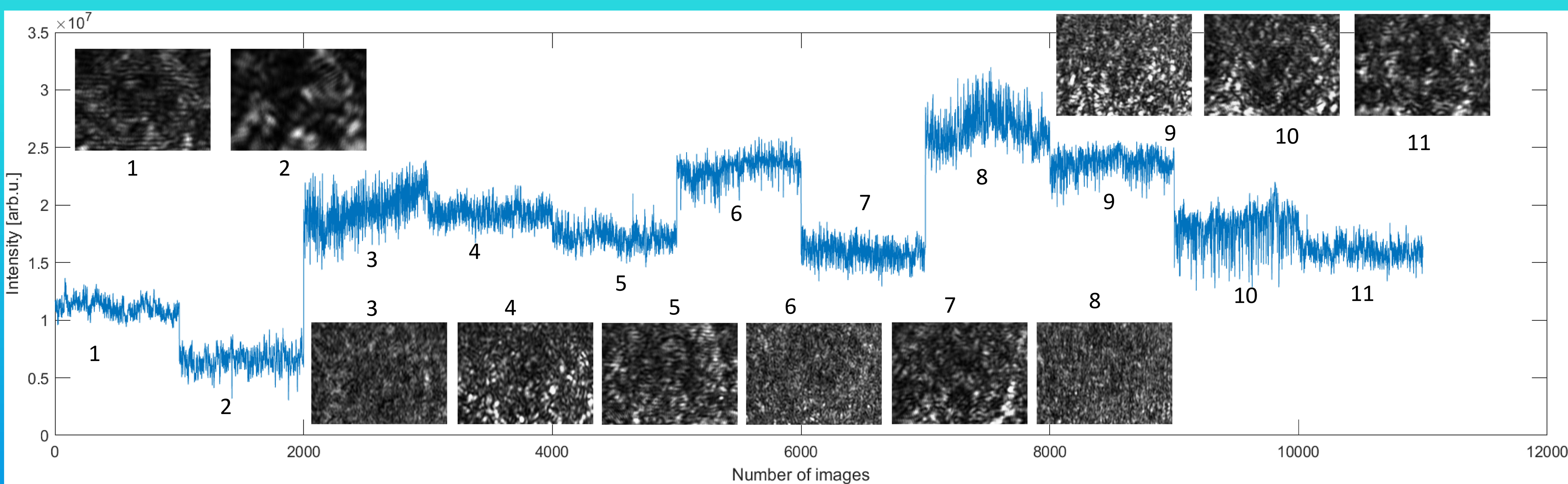
We produced single microdroplets from colloidal suspension of Gd_2O_3 : 1% Nd (ø= 305 nm) nanoparticles in diethylene glycol (DEG) using an in-lab built droplet-on-demand injector. The droplets were levitated in a linear electrodynamic trap (shown above) and illuminated vertically with a red laser (wavelength, 658 nm). A 15 mm focal length imaging lens was used to magnify the droplet such that the speckles from the nanoparticles, around a 90^{o} angle to the illumination direction, can be registered on the CCD. A combination of factors such as trap geometry, weak intensity from the nanoparticles, the influence of higher intensities from the droplet's glory points and the inverse relation between the speckle size and aperture diameter dictated the recording of optimum speckle size at a longer distance of 420 mm from the lens. An aperture of 0.5 mm was used to cut off the higher intensities from the glory points on the droplets. A trapped droplet was allowed to evaporate under standard room conditions and 1000 speckle patterns were recorded at different times during evaporation. In a similar measurement, approximately equal sizes of droplets were produced but from different concentrations (5, 10, 20 30 and 50 mg) of the nanoparticles in DEG as well as same concentration different droplet diameters. Shadowgraphy was used to estimate the droplet size. In this measurement, the droplets evaporation and size change was very minimal. The speckle patterns were normalised to 0-1 range and a convolutional neural network was trained for classification.

Results

Preliminary analysis of the recorded speckle patterns – thus the classificaton of the normalised images revealed the possibility to classify droplets of different concentrations; also apart from the observable difference in speckles, the sum of the intensities over each pattern show different modulations at different times of the evaporation.

Outlook

Changes in concentration over the entire evaporation may be categorised using the retrieved initial radius and concentration of the droplet.



Sum of intensities calculated over each image plotted for 11 instances of measurements during evaporation, the numbers match the sample images to their corresponding regions

[1]. Woźniak, M., Archer, J., Wojciechowski, T., Derkachov, G., Jakubczyk, T., Kolwas, K., ... & Jakubczyk, D. (2019). Application of a linear electrodynamic quadrupole trap for production of nanoparticle aggregates from drying microdroplets of colloidal suspension. *Journal of Instrumentation*, *14*(12), P12007..

[2]. Wozniak, M., Derkachov, G., Kolwas, K., Archer, J., Wojciechowski, T., Jakubczyk, D., & Kolwas, M. (2015). Formation of highly ordered spherical aggregates from drying microdroplets of colloidal suspension. *Langmuir*, *31*(28), 7860-7868.