Non-contact measurement of surface tension on single droplet: combining machine learning and acoustic levitation

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INTRODUCTION: Surface tension, a central feature for a wide variety of applications, is traditionally measured through methods that imply direct contact with a solid surface. Acoustic levitation allows the allocation of small volume samples (< 5 μL) in mid-air, through which surface related shortcomings can be avoided. Depending on the applied acoustic pressure (*i.e.*, driving voltage), together with the volume and surface tension of the droplet, its shape will differ (Fig. 1). Similarly, to the pendant drop method it is possible to determine the surface tension from its deformation under constrain; however, the pressure on the surface of the droplet needs to be known. This is a parameter that is not easily accessible with high accuracy. For that reason, we used a data-driven approach by implementing a deep neural network (DNN) to predict the surface tension.

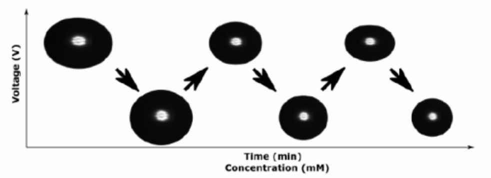

Fig. 1: Photos of droplets at different volumes, surface tension, and applied voltage. The white circle at the center is the reflection from the light source [1].

METHODS: We prepared surfactant solutions (10^{-3}-10 mM) and determined the surface tension through the pendant drop method (30 – 72 mN/m). Following, we used a highly stable acoustic levitator to evaporate single droplets at different surfactant concentrations, while varying the driving voltage with a rate of 0.1 V/sec. During evaporation the surface tension of the sample decreased, due to the increase in surfactant concentration. We collected a total of over 50,000 photos where 40,000 were used as a training dataset, and the rest were used for the evaluation of the DNN. We used in-silico generated droplet contours to test the influence of experimental noise on the machine learning (ML) predictions of surface tension. Lastly, we implemented a machine learning *feature importance* algorithm to investigate which input features (contour, voltage, *etc.*) were influencing the neural network outcome.

RESULTS: The DNN predicted the surface tension of surfactant solutions within the range of 30 – 72 mN/m, with a mean absolute error of 0.9 mN/m (Fig. 2a). The algorithm performed equally well on all types of surfactants (anionic, non-ionic, and cationic). Furthermore, the feature importance algorithm indicated the regions of the droplet that contributed the most to the predictions (Fig. 2b), while the features that were following in importance were the voltage, current, and the vertical position of the droplet [1].

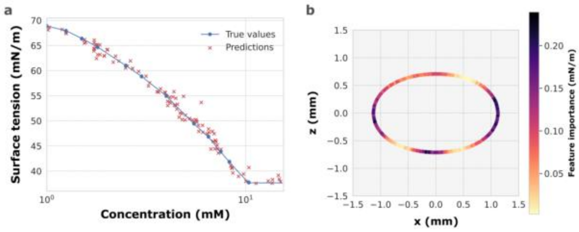

Fig. 2: a) Surface tension determined through the pendant drop method (blue line) and predicted through the DNN (red x), b) color coded droplet regions based on their contribution to the ML predictions of surface tension [1].

DISCUSSION & CONCLUSIONS: We demonstrated the capability of a DNN to predict the surface tension of acoustically levitated droplets. The feature importance algorithm provided insights into the features that the neural network used to predict the surface tension. The average mean absolute error was below 1 mN/m which provided the possibility to measure the critical micelle concentration by using a single evaporating droplet of surfactant solution.

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REFERENCES: [1] Argyri, S. M., Evenäs, L., & Bordes, R. (2023). Contact-free measurement of surface tension on single droplet using machine learning and acoustic levitation. Journal of Colloid and Interface Science, 640, 637-646.