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Physics-informed neural networks for the prediction of hidden fluid mechanics in droplet impingement

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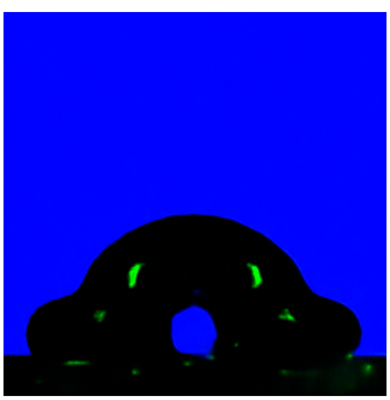
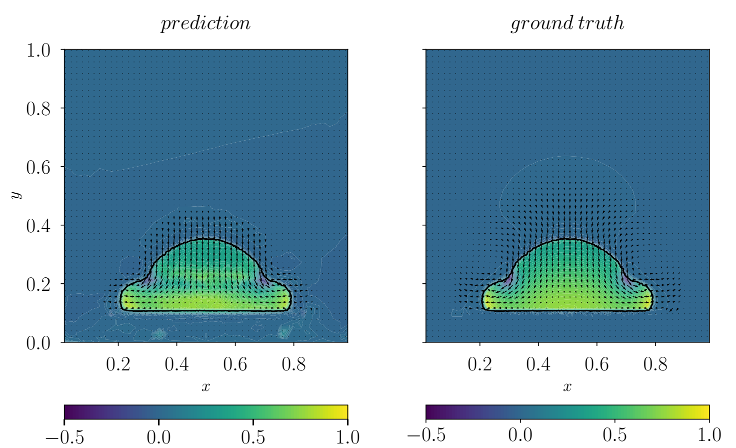
Droplet impingement constitutes a significant phenomenon in numerous technical processes, including spray cooling, spray coating, and combustion. Mastery of this phenomenon is key to optimizing performance and efficiency in these processes – a comprehensive understanding of the interaction between droplets and walls is still pending. Optical experimental methodologies, such as shadowgraphy technique and particle image velocimetry can provide insight through the measurement of the gas-liquid interface and internal velocity fields, respectively. These experiments, however, are constrained to planar measurements, whereas the droplet dynamics are inherently three-dimensional, especially during droplet impingement on structured or inclined surfaces.

In the preceding work, a data-driven approach utilizing physics-informed neural networks (PINNs)[1] and an advanced shadowgraphy technique with lateral glare points[2] was developed. Our novel approach is aimed at the prediction of the volumetric shape, velocity and pressure fields from an image sequence recorded with the color-coded shadowgraphy technique. This method allows for the encoding of additional three-dimensional information for the volumetric reconstruction of the deforming gas-liquid interface during droplet impingement[3]. The approach is extended to the prediction of a three-dimensional flow by the integration of the single-field, two-phase formulation of the Navier-Stokes equations, akin to the Volume-of-Fluid method into the physics-informed part of the PINNs and the introduction of additional visual input data.

One snapshot of the synthetic validation data set can be seen in Fig. 1a, while a two-dimensional slice of the predicted pressure field for this snapshot is shown in Fig. 1b, with the prediction on the left compared to the ground truth pressure on the right. As can be seen, there is a good topological and quantitative agreement between the prediction and the ground truth. Similar results were obtained for the predicted velocity fields. The results for the reconstruction of the droplet dynamics demonstrate the feasibility of the simultaneous prediction of the three-dimensional gas-liquid interface, as well as the velocity and pressure fields from experimental image data with the presented approach. In the conference contribution we will address further metrics of reconstruction, especially the accuracy, which will be evaluated on the basis of images recorded in the experiments.



(a) Synthetic input image rendered from a simulated droplet during impingement.



(b) Predicted velocity vector field and pressure contours along the center plane of the droplet (left) in comparison to the ground truth simulation data (right). The contour of the gas-liquid interface is indicated by the black solid line.

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[1]Raissi et al., *Science* **367, 1026-1030** (2020).
[2]Dreisbach et al., *Measurement Science and Technology* **64** (2023).
[3]Dreisbach et al., *arXiv preprint* **2310.16009** (2023).