Simultaneous 3D Lagrangian Particle Tracking of bubbles and fluid tracer particles in a bubbly water jet

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The experimental investigation of two-phase flows by means of particle-based optical field measurement techniques like PIV or Lagrangian Particle Tracking (LPT) pose significant challenges. Typically, the tracer particles within the fluid phase (e.g. water, air) are much smaller (Stokes numbers << 1), compared to the objects in the other phase (e.g. bubbles, solid particles, else). The illumination required to visualize the tracer particles therefore often significantly overexposes the larger objects, inhibiting a precise localization of both particle regimes. In such flows the grade of complexity for the particle position reconstruction and -tracking process even increases when applying 3D PIV or -LPT techniques using several camera projections. Two-phase turbulent flows are widely used in engineering and environmental applications (Balachandar & Eaton 1993; Mathai, Lohse & Sun 2020). This study describes a method for simultaneous measurements of time-resolved three-dimensional velocity and acceleration fields of the dispersed and continuous phases of a turbulent bubbly jet flow at a low void fraction using 3D LPT with the Shake-The-Box algorithm (Schanz et al. 2016, Schröder & Schanz 2023). Four high-speed cameras are used to acquire time series of images that include both bubbles and fluid tracer particles illuminated by a combination of two pulsed illumination sources with different intensities (see Fig. 1). A pulsed UV- LED array excites fluorescent tracer particles, which are imaged by four high-speed cameras using optical low-pass filters and a dimmer white-light LED array illuminates the bubbles (which are invisible for the cameras in the fluorescent light), leading to well exposed bubble and tracer images in the same image series. Bubbles are firstly tracked using intensity differences between tracer particles and bubbles, then the bubble images are removed from the camera images and all tracer particles are tracked using the residual images. Subsequently, FlowFit data assimilation (Gesemann et al. 2016) is applied to the obtained LPT results by phase separation to investigate the flow characteristics of the bubbly jet. This contribution is aiming at describing mainly the experimental set-up using two different LED arrays and fluorescent tracer particles and the image processing methods.

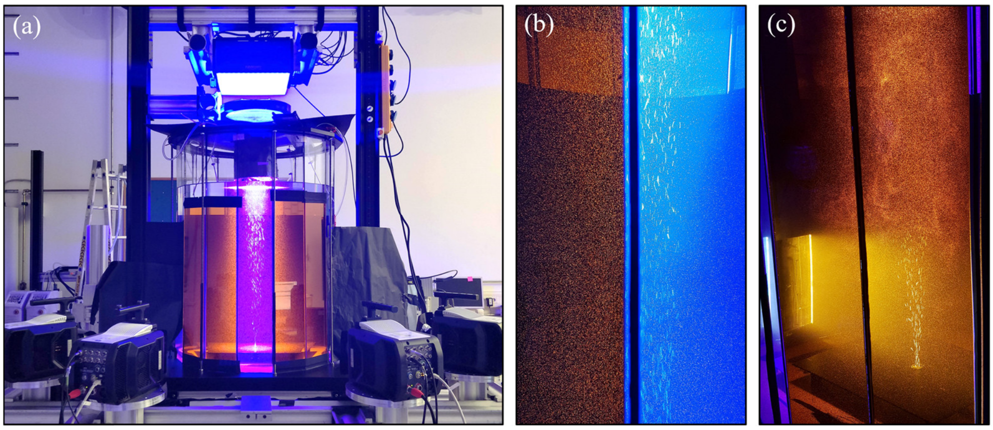

Fig. 1: (a) Overview showing the tank, the UV- illumination (top) for the fluorescent tracers in the fluid phase, the orange lowpass-filters applied to four of the glass windows and the camera setup; (b) simultaneous view through two glass plates with and without filter, illustrating the filtering effect on the bubbles (only UV- LEDs on); (c) view through two of the orange filters, illustrating the effect of bubble visibility by the low-intensity white illumination, coming from the side at the bottom part of the tank (UV- and white LEDs on)

First fluid mechanical analyses of the flow dynamics and bubble properties stemming from the described experiment are already presented in Kim et al. 2022.
In order to successfully triangulate (and then track) a bubble from the recorded images, the following image preprocessing was applied. The image of a single bubble consists of two glare points, which are the reflections on the inner and the outer interface of the bubble. The distance of the two glare points is determined by the bubble size, given a fixed magnification, and the angle of the camera relative to the white LED illumination. In order to identify the bubbles mid-point positions, the camera images were correlated with a calibrated 2D kernel for each camera view, yielding a central peak with weaker side peaks. In order to enhance the central peak, the image was squared (enhancing contrast) and finally a Gaussian smoothing was applied. From these images, the bubble positions could be triangulated and STB was able to track almost all bubbles along their entire trajectories through the measurement volume. Once the bubble field was tracked, the images of the bubbles were eradicated from the camera images by back-projecting the found 3-D positions onto the different cameras using the 3-D calibration and subtracting an extended Gaussian peak around the projection point. As a result, the images of the bubbles are completely removed and STB tracking can be performed on pure tracer particle images. In the end, both phases, the bubbles and tracer particles, could be tracked individually and simultaneously in the entire measurement volume. Typically, around 90,000 tracer particles and a few hundred bubbles could be tracked instantaneously and an optimal temporal filter using third-order B-splines (Gesemann et al. 2016) was applied to determine velocity and acceleration of the tracked bubbles and particles. In Fig. 2 a snapshot out of a time series of instantaneously tracked particles and bubbles are shown color coded by the vertical velocity.

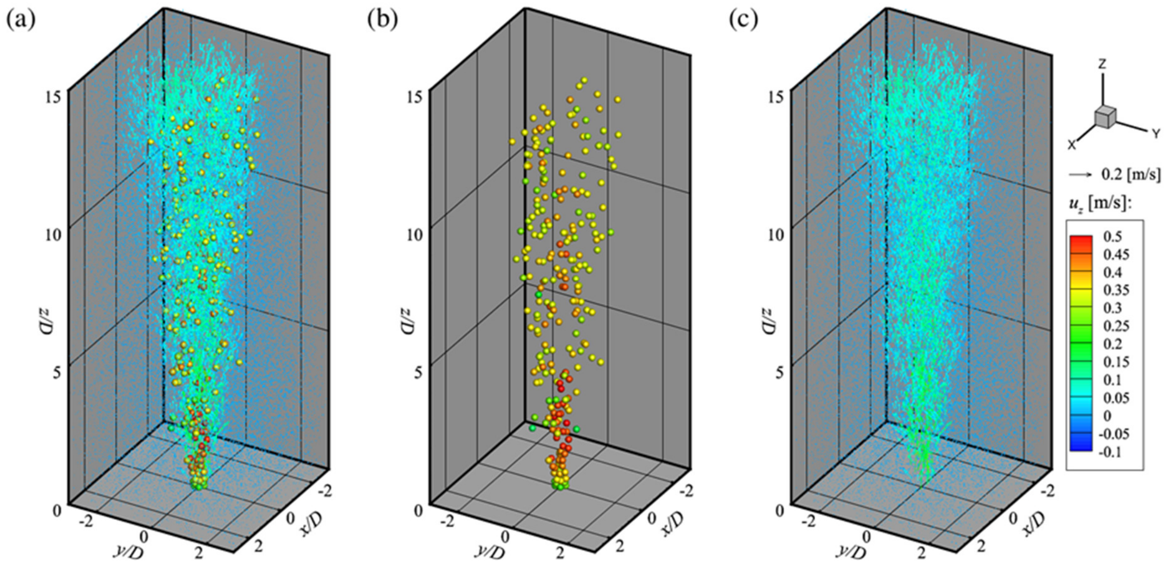

Fig. 1: Lagrangian bubble-particle tracking and phase separation results presnted for (a) simultaneous measurement, (b) bubbles, (c) tracer particles.

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