

IN APPLICATION

Time-resolved 3D Imaging of Bubbly Flows based on Tomographic Shadow Imaging

ParticleMaster 3D Shadow System

Introduction

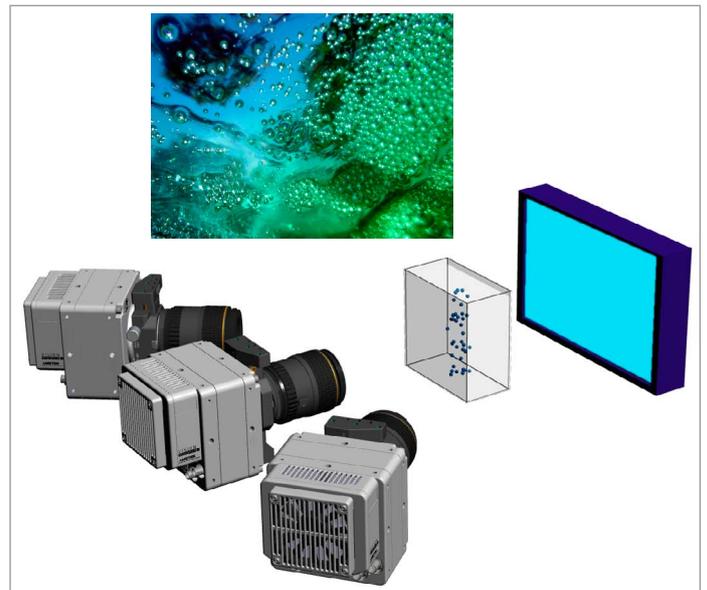
In recent years there is a growing interest in the flow behavior of dispersed multiphase flows featuring complex 3-dimensional (3D) fluid mechanical processes. For 2D imaging of such flows planar PIV is applied on laser light sheets for velocity measurements in the liquid phase and shadow imaging for shape, size and velocity information of the bubbles. With time-resolved tomographic shadow imaging the measurement domain is extended into 3D space allowing simultaneous and time-resolved 3D measurements of gas-liquid flows without signal cross talks between both phases known from e. g. laser light sheet illumination strategies.

Measurement Principle and Experimental Setup

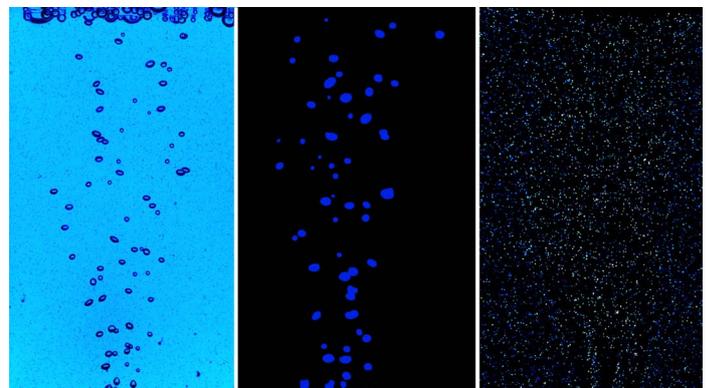
Tomographic shadow imaging is used to reconstruct the bubbles in 3D space as well as the locations of the much smaller seeding particles dispersed in the liquid phase. Phase separation is performed using a software filter sensitive to the size difference between the seeding particles and the bubbles.

LaVision's pulsed **Blue LED Backlight** is used for backlight illumination of the bubbly flow inside a cuvette. The flow itself is generated by the rising bubbles in the water tank. Three high-speed cameras capture the shadow images of the bubbly flow from different directions at a recording rate of 500 frames per second. The short flash duration of the backlight is synchronized with the exposure time of the cameras and freezes the flow motion without image blur.

A highly accurate camera calibration in space is necessary for tomographic imaging and is realized with LaVision's **Volume Self-Calibration** method in **DaVis**. After camera calibration and image recording various image processing steps are carried out to separate the bubbles from the smaller seeding particles. Finally, for both phases, the three shadow projections are used to reconstruct the bubbles as well as the seeding particles in 3D space for each time step. From these time-correlated 3D images the 3D velocity tracks of the bubbles as well as the 3D flow field of the liquid phase are calculated applying LaVision's **Shake-the-Box** particle tracking algorithm.



High-speed tomographic shadow imaging setup investigating multiphase flows in 3D.



Phase separation in DaVis: both phases (left), bubble flow (middle) and liquid flow (right).

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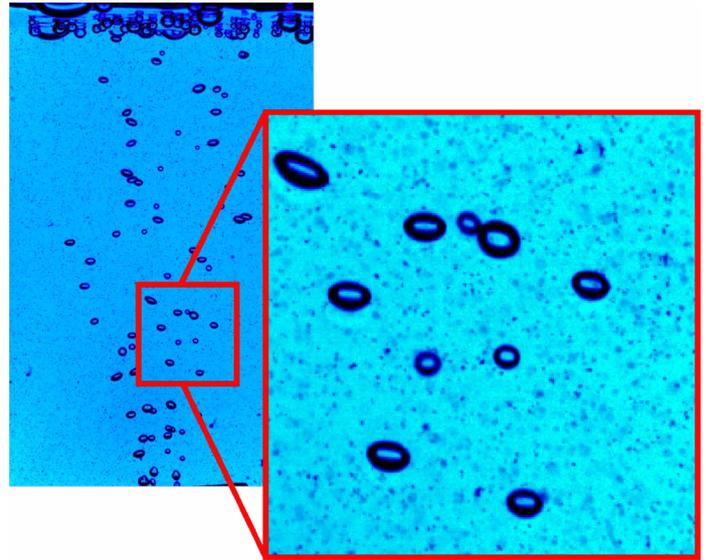
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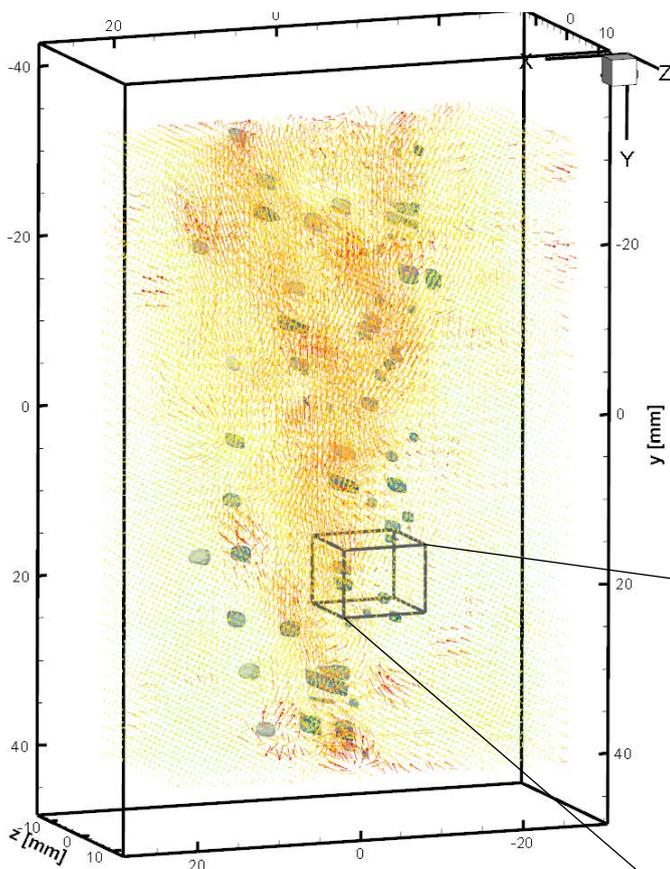
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Results

The image below shows a 3D snapshot of a recorded high-speed image sequence of the two phase flow showing nicely the interaction between the rising bubbles and the induced flow field in the water tank. The presented tomographic shadow imaging technique is scalable in space and time: larger and smaller volumes can be investigated depending on the desired spatial resolution. The void fraction of the bubbles can be increased until decreasing transparency for each line-of-sight projection is limiting the quality of tomographic reconstruction process. The recording rate of the cameras can be increased to study faster flow phenomena at a higher time resolution.



Zoomed shadow image of bubbles and seeding particles. Bubble images show the backlight as a bright internal spot.



Snapshot of a time-resolved 3D presentation of a bubbly flow with a zoomed detail

ParticleMaster 3D Shadow System Features

- ▶ 3D imaging based on tomographic shadowgraphy
- ▶ phase separation based on shadow image size only
- ▶ state-of-the-art **"Shake-the-Box"** 4D-PTV algorithm
- ▶ bubble shape, size and velocity
- ▶ 3D velocity and acceleration field of the liquid phase
- ▶ only one backlight for volumetric illumination
- ▶ TecPlot™ presentation of both phases in one coordinate system

