3D path tracking of particles in a swirling flow using a light-field camera

S. Ostmann1*, H. Chaves1, C. Brücker1

1: Department of Mechanics and Fluiddynamics, University of Freiberg, Freiberg, Germany
* correspondent author: stefan.ostmann@imfd.tu-freiberg.de

Keywords: Particle Tracing Velocimetry (PTV), Plenoptic, lightfield camera

It is well known that bluff bodies in flows at higher Reynolds numbers (Re~10^3) induce wakes. In case that the body is free to move such as for a particle in flow and that its density is low compared to the surrounding fluid, the particle path will be affected by the wake instabilities. For bubbles rising in liquids the trajectory can be straight but also be in the form of a zigzagging or spiraling path. These paths shall be examined using time resolved 3D-PTV. In the last years, the method of light field recordings using Plenoptic cameras has grown in interest. Herein we use such a method in combination with shadowgraphy. A Plenoptic lens consists of an array of micro lenses orthogonally to the main optical axis. The so recorded sub images could be understood as a different section of the light field spreading out as spherical wave originating from any surface in the object space. These sub-images distinguish each other through a slightly differing angle of view, resulting in a small parallax in the imaging plane (Adleson Edward H. 1992).

Experimental Setup

For the study of 3D trajectories of particles in liquids a rotating vertical pipe with a diameter of D=500 mm and a length of L= 5 m is available. This device offers the opportunity of long observation times through a vertical movable sled. So it could be assured to observe the wake instabilities over a long time-span. The optical design was simulated using the optical design software RADIANT ZEMAX©. Due to the character of the used retro reflective layer, light rays are reflected back in the exact angle of impact. For the simulations we assume an ideal working retro layer with the consequence that the beam path for illumination has to correspond the beam path of observation exactly. According to the supposed ideal condition of the retro layer, the angular light field has to be created artificial. So a number of light sources equal to the number of micro lenses are needed. Any of the non-centered light sources is tilted about 5° towards the center light source.

Camera Calibration and Position Tracing

For camera calibration the method after Soloff et. al. (Soloff 1997) was applied. This method uses a set of points and their corresponding coordinates in object space to interpolate two 3-dimensionel polynomials with cubic dependence in X and Y direction and square dependence in direction of the depth coordinate (Z), as a functions of X, Y, and Z. The correspondant points in the image space. Whereupon the mean error of the center image is slightly lower than in the rear images whose error ranges are between 0.19 and 0.21. Considering the error dimensions, it could be stated, that the accuracy of the measurement system has subpixel accuracy.

Due to the presence of dragging slices, which means lines of sight with a vanishing relative angle to each other, a method for determination of the center of mass has to be found. A common approach for systems without dragging slices would be to calculate the distance of all lines of sight for arbitrary points of Z, considering the minimum the position of the center of mass. This approach is insufficient due to near parallel path of the lines of sight (dragging slices), so we assumed that in the striking distance of the center of mass in object space the number of intersections becomes a maximum with respect to the depth coordinate (Z).

Results

The algorithm used for center of mass triangulation shall be understood as a fast approximation procedure to be either used to get an idea of the experimental conditions or as first guess for further computations as a 3D reconstruction in connection with 3D cross correlation of the center of mass within the voxel volume, which is considered to be more accurate than the presented way. It may be expected, that the accuracy of the presented way of triangulation could be increased by the use of a larger lens array in a sense of the number of used micro lenses.

Fig. 1 Ray Path through measurement area (simulated with RADIANT ZEMAX©)

Fig. 2 Model of the Vortex-Channel

Fig. 3 Euclidean Norm of rear Projection (error in pixels)

Fig. 4 3D Trajectory of a rising particle